Transforming U.S. Energy Innovation

Appendices

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Ruud Kempener, Audrey Lee, Nathaniel Logar, & Venkatesh Narayanamurti

HARVARD Kennedy School

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November 2011

Energy Technology Innovation Policy Research Group

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Our efforts have been greatly enriched by the time and the wisdom that our ERD3 Board has so generously provided over the course of this project.

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All responsibility for any errors or misjudgments rests solely with the authors.

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Experts' judgment of technology cost and performance

Our analysis depends on the experts' judgment of current and future technology cost and performance. We obtained expert opinion about likely commercially viable technologies by expert elicitation. We present the results of our elicitations for each technology area in our portfolio—bioenergy for liquid transportation fuels and power production, grid-scale energy storage, nuclear power, fossil fuel power production with and without carbon capture and storage, buildings technology, light duty vehicles, and photovoltaics. We are able to assess expert bias, if any, towards allocating money and RD&D resources towards technologies of which they proclaim leading expertise. We are also able to determine average or representative allocations of RD&D budgets as well as expected outcomes for changes in RD&D funding.

A.1. Bioenergy for liquid transportation fuels and power production

We would like to thank the participating experts (Table A-1) for generously sharing their time and expertise. We randomly assigned each a number between 1 and 12 in our results.

Name	Affiliation
David Austgen	Shell
Joe Binder	UC Berkeley
Harvey Blanch	UC Berkeley
André Boehman	Penn State University
Robert Brown	Iowa State University
Randy Cortright	Virent

Name	Affiliation
Eric Larson	Princeton
Lee Lynd	Dartmouth
Tom Richard	Penn State University
Phillip Steele	Mississippi State University
Bob Wallace	Penn State University
Bryan Willson	Solix

TABLE A-1. Experts who completed the elicitation about bioenergy for liquid transportation fuels and power production

Conversion technology	Refining technology	Biofuel
Gasification	Catalytic reforming	Ethanol
Hydrolysis	Hydrotreating	Methanol
Hydrothermal upgrading	Transesterification	Butanol
Liquefaction	Cross-transesterification	Dimethyl ether
Pyrolysis	Fermentation	Fatty acid methyl ether
	Membrane separation	Bio jet fuel
	Micro-emulsification	
	Solvent-based extraction	

TABLE A-2. Technologies and biofuels presented to experts

We asked experts to estimate cost and performance of processes to produce substitutes for conventional gasoline, diesel, jet fuel, and electricity in 2010 and in 2030 if federal funding and policy for bioenergy RD&D does not change over the 20-year period, as well as in 2030 for varying levels of their recommended budget and allocation. This budget and allocation is based on how they assigned an annual budget among the technologies in Table A-2.

We compared experts' budget recommendations against their self-assessed expertise per technology and conclude that there is insignificant bias in their budget allocations towards their areas of expertise. As shown in Figure A-1, experts were not biased to funding those areas in which they had high levels of expertise (4 and 5). Most experts recommended funding areas in which they had lower expertise levels. The only manifestation of bias is that experts did not recommend zero funding for areas for which they had rated themselves as having the highest levels of expertise (levels 4 and 5).

The average annual spending recommendation among the experts is $680 million. The experts recommended a range of funding for bioenergy technology basic research, applied research, experiments and field demonstration, and commercial demonstration. Experts designated the "Other" technology category in the allocation as enhancing biochemical technologies, developing transportation technologies that can use liquid fuels that are not perfect substitutes for conventional fuels, fossil fuel refining

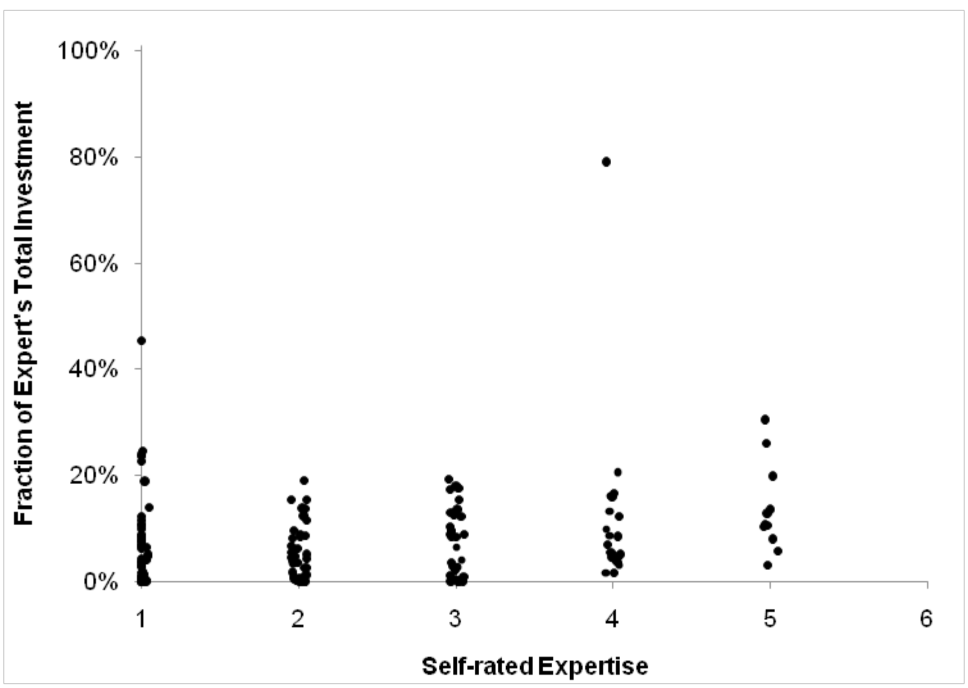


FIGURE A-1. Analysis of bioenergy expert bias in budget allocation toward their areas of expertise. Each point corresponds to the fraction of the recommended budget that an expert devoted to a particular technology (y-axis) and the expert's self-assessment of his level of expertise in the same technology (x-axis). The increasing density of the circles shows greater number of experts with same level of expertise and budget allocation to a given technology.

and conversion technologies, and feedstock genetics, harvest, and transport. We show the group's recommended funding allocation as dollar and percentage allocation of the experts' budgets. Figure A-2 shows the range of absolute budget allocation among the twelve experts who participated in the survey. We plot minimum, mean, and maximum allocation amount per innovation stage and technology, as well as 25th and 75th percentiles. Figure A-3 shows the values for the mean budget allocation, by innovation stage and technology, shown in Figure A-2. Figure A-4 shows the same information as percentage of total budget. As shown in Figures A-2 through A-4, on average the experts thought that bioenergy funding should focus on basic research and commercial demonstration for gasification, commercial demonstration for hydrolysis and pyrolysis, and commercial demonstration for "other".

Figures A-5 and A-6 show the gasoline cost and yield that experts predicted in 2030 under BAU spending and their recommended spending, compared to their estimates of cost and yield in 2010. As Figure A-6 shows, experts predict between 11–80% reduction in 50th percentile gasoline substitute production

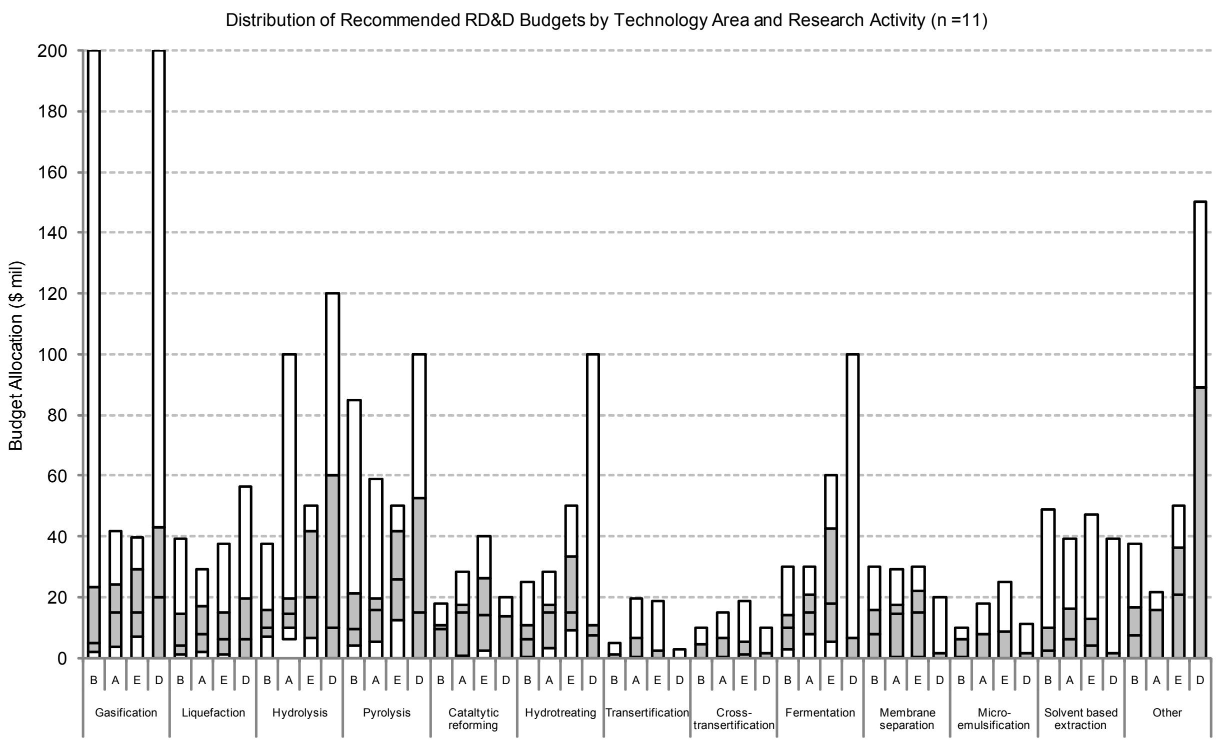


FIGURE A-2. Minimum, average, and maximum allocations over all experts per technology and innovation stage (million 2009$). Gasif=Gasification, Lique=Liquefaction, Hydro = Hydrolysis, Pyrol = Pyrolysis, Catal = Catalytic reforming, Hydro = Hydrolysis, Trans = Transesterification, Cross = Cross-transesterification, Ferme = Fermentation, Membr = Membrane separation, Micro = Microemulsification, Solve = Solvent extraction. Basic = basic research, Applied = applied research, ExpPilots = experiments and field pilots, C Demo = commercial demonstration. Note that we collected a sample of experts that is representative of the field rather than a "statistically representative" sample. As such, each expert's opinion is an individual viewpoint in the field. However, we chose to show an "average" of the recommended percentage allocation because the maximum and minimum are extreme in many cases; the minimum budget allocation for a given technology is 0 percent in all cases but one: applied research in hydrolysis.

	Conversion				Refining								Others
	Gasification	Liquefaction	Hydrolysis	Pyrolysis	Catalytic reforming	Hydrotreating	Transertification	Cross-transertification	Fermentation	Membrane separation	Micro-emulsification	Solvent based extraction	Other
Basic Research	29.0	9.3	13.0	20.0	6.8	7.3	1.0	2.2	10.7	10.5	3.2	7.9	10.0
Applied Research	15.4	10.8	22.9	16.6	12.0	11.7	4.6	3.7	14.6	10.9	4.5	10.4	7.8
Experiments and Pilots	17.7	10.8	23.3	26.9	15.8	20.5	2.6	4.0	23.7	13.5	5.9	11.1	20.3
Commercial Demonstration	37.4	13.4	32.5	32.3	6.6	16.1	0.3	1.7	14.3	3.4	1.7	4.3	45.2
Total	91.2	40.6	84.0	87.8	37.8	50.9	7.7	10.6	58.0	35.1	14.0	31.0	76.3

FIGURE A-3. Average Allocation of Recommended Annual Federal Bioenergy RD&D Budget for 2010 – 2030 (million 2009$). One expert's recommendations were removed from the average because his/her total recommendation was orders of magnitude higher and would have disproportionally skewed the average. This expert's percentage allocation, however, is included in the figure following.

	Conversion				Refining								Others
	Gasification	Liquefaction	Hydrolysis	Pyrolysis	Catalytic reforming	Hydrotreating	Transertification	Cross-transertification	Fermentation	Membrane separation	Micro-emulsification	Solvent based extraction	Other
Basic Research	4.7	1.2	2.0	2.4	1.4	1.2	0.2	0.3	1.9	1.8	0.5	1.1	1.3
Applied Research	1.9	1.6	3.9	2.3	2.1	1.9	0.6	0.5	2.3	1.7	0.6	1.4	1.2
Experiments and Pilots	2.7	1.6	3.3	3.7	2.3	2.8	0.4	0.6	3.7	2.4	1.0	1.4	3.0
Commercial Demonstration	5.9	1.7	4.0	3.7	1.1	1.7	0.2	0.5	1.7	0.8	0.5	0.7	6.6
Total	15.3	6.0	13.1	12.1	7.0	7.6	1.4	1.9	9.6	6.7	2.6	4.6	12.0

FIGURE A-4. Average Allocation of Recommended Annual Federal Bioenergy RD&D Budget for 2010 – 2030 (percent of total budget) costs by 2030 (with one expert projecting a rise in costs). The EIA AEO 2010 forecasted cost to produce conventional gasoline, \$3.68/gallon, falls within the range of 6 experts' predicted 2030 gasoline substitute production costs but 6 experts' ranges are below the AEO projected conventional gasoline production cost. The 50th percentile cost to produce a gallon of gasoline substitute is expected to range from \$0.75–\$5/gallon in 2030. An additional decrease in cost can be gained by implementing experts' recommended budgets, which results in a \$0.20–\$2.50 per gallon production costs. Figure A-6 shows that the experts expect 2030 50th percentile conversion yields for biomass-based gasoline substitutes to range from 50–140 gallons per dry ton of feedstock, and increase by 10–56% over 2010 conversion yields.

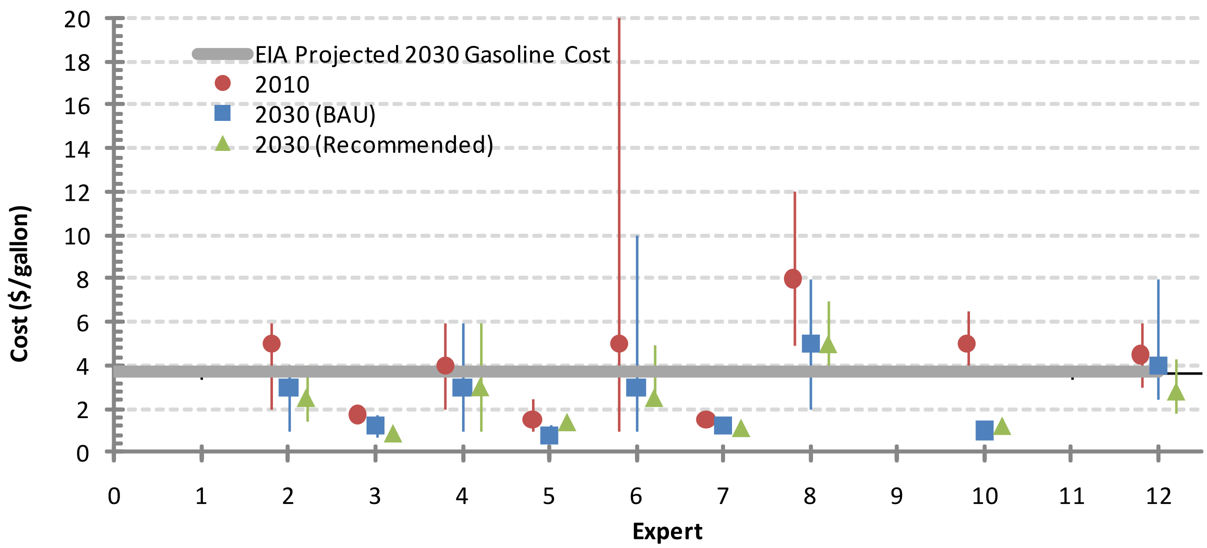


FIGURE A-5. Expert 2010 gasoline substitute production cost, predicted 2030 gasoline substitute production costs under business-as-usual budget, and recommended budget. The 2030 conventional gasoline cost predicted by the EIA AEO 2010 is \$3.68/gallon. The plot shows the 10th, 50th, and 90th percentile estimate per each expert.

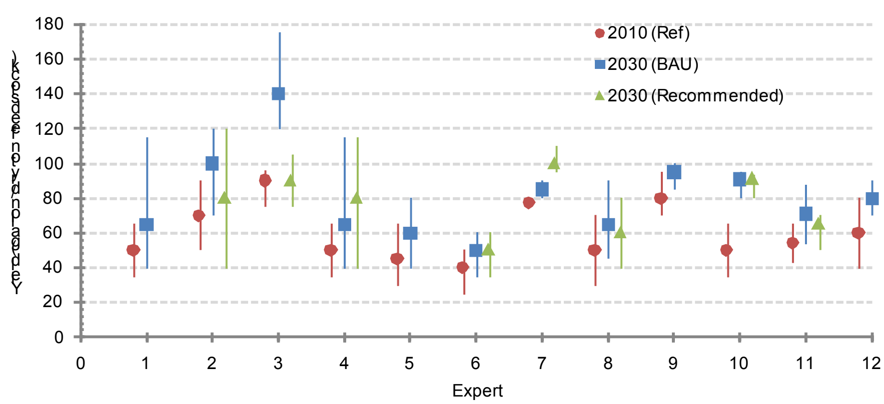


FIGURE A-6. Expert 2010 gasoline substitute conversion yield, predicted 2030 gasoline substitute conversion yields under business-as-usual budget and recommended spending. The plot shows the 10th, 50th, and 90th percentile estimate per each expert.

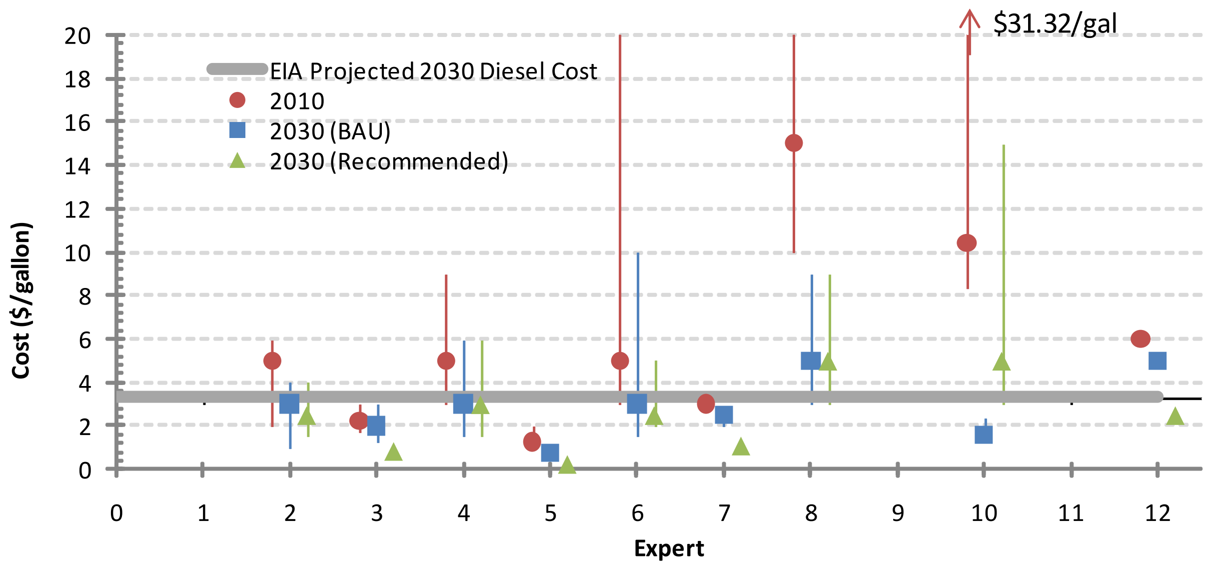


FIGURE A-7. Expert 2010 diesel substitute production cost, predicted 2030 diesel substitute production costs under business-as-usual budget and recommended spending. The 2030 conventional diesel cost predicted by the EIA AEO 2010 is $3.31/gallon. The plot shows the 10th, 50th, and 90th percentile estimate per each expert. Expert 9 did not provide estimates of 2010 or 2030 diesel substitute production cost.

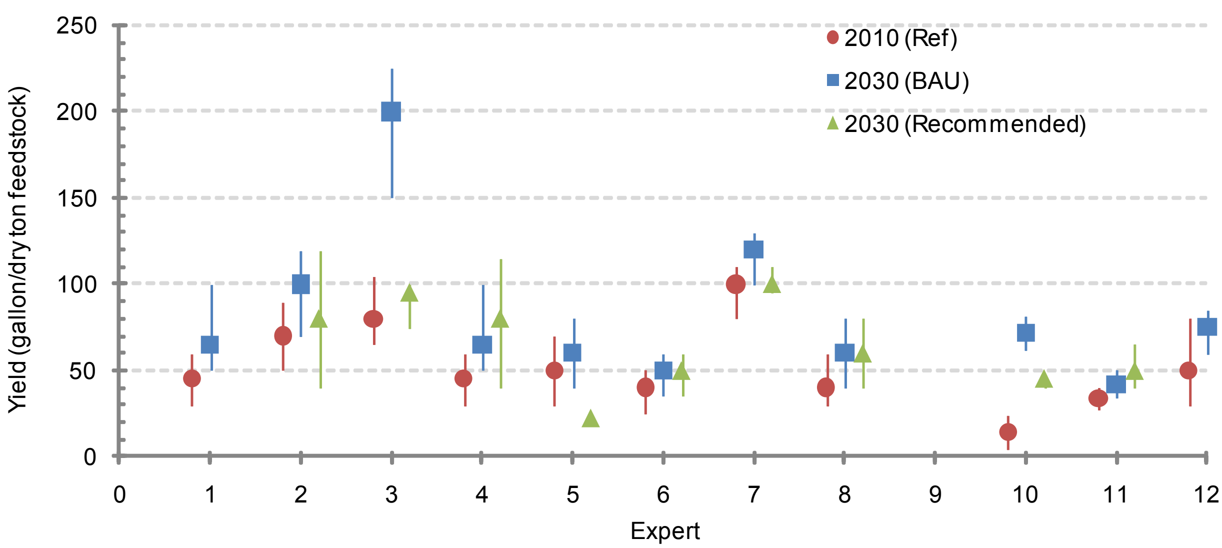


FIGURE A-8. Expert 2010 diesel substitute conversion yield, and predicted 2030 diesel substitute conversion yields under business-as-usual budget and recommended budget. The plot shows the 10th, 50th, and 90th percentile estimate per each expert. Expert 9 did not provide 2010 or 2030 diesel substitute conversion yields.

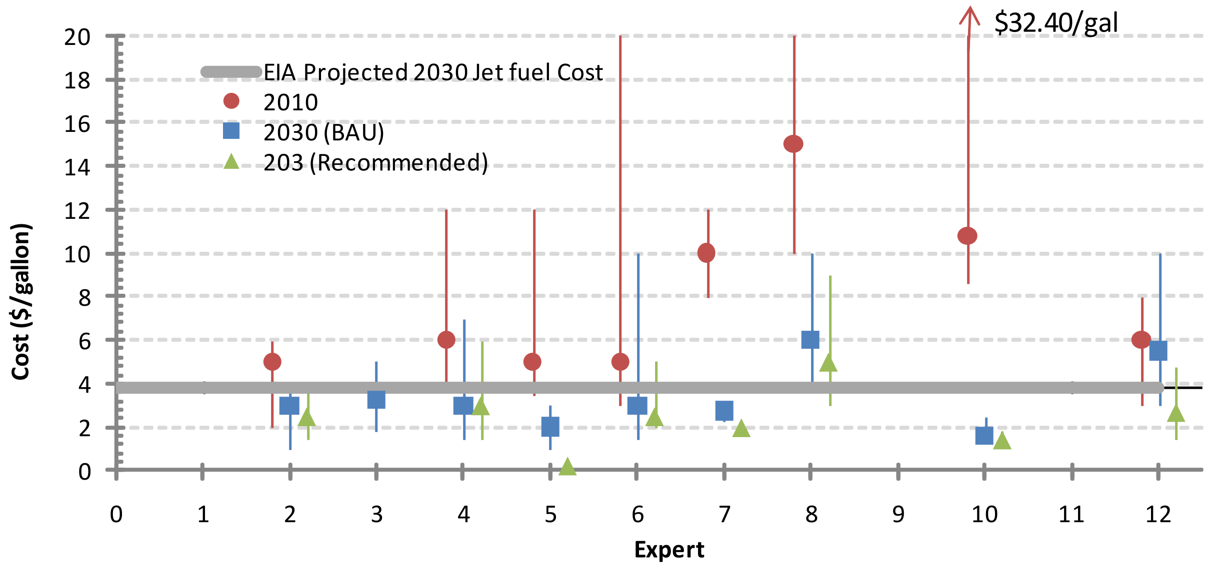


FIGURE A-9. Expert 2010 jet fuel substitute production cost, predicted 2030 jet fuel substitute production costs under business-as-usual budget and recommended spending. The 2030 conventional jet fuel cost predicted by the EIA AEO 2010 is $3.83/gallon. The plot shows the 10th, 50th, and 90th percentile estimate per each expert. Expert 9 did not provide 2010 or 2030 jet fuel substitute production costs.

Implementing experts' budgets will result in 50th percentile conversion yields ranging from 50–100 gallons per dry ton of feedstock.

Figures A-7 and A-8 show how the diesel cost and yield that experts predicted in 2030 under varying spending scenarios compared to their estimates of cost and yield in 2010 under business as usual funding. Figure A-7 shows that the EIA AEO 2010 projected cost of producing conventional diesel in 2030, $3.31/gallon, falls within the 7 experts' estimated range of diesel substitute production cost. We can see that as a group the experts believe that 50th percentile diesel substitute production costs will decrease by 11 to 85% by 2030. Spending the experts' recommended budgets would result in diesel substitute production costs of $0.25–$5.00 per gallon by 2030. Figures A-8 shows that the experts expect 2030 50th percentile conversion yields for biomass-based diesel substitutes to range from 42–200 gallons per dry ton of feedstock, and increase by 20–400% over 2010 conversion yields. If the experts' recommended budgets were implemented, 50th percentile diesel substitute conversion yields would range from 23–100 gallons per dry ton of feedstock.

Figures A-9 and A-10 show the jet fuel cost and yield that experts predicted in 2030 compared to their estimates of cost and yield in 2010 under business as usual funding. Figure A-9 shows that the EIA AEO 2010 projected cost of producing conventional jet fuel in 2030, $3.83/gallon, falls within the 7 experts' estimated range of jet fuel substitute production cost. We can see in that as a group the experts believe that 50th percentile jet fuel substitute production costs will decrease by 8 to 85% by 2030. Implementing experts' recommended budgets will result in a 50th percentile jet fuel substitute pro-

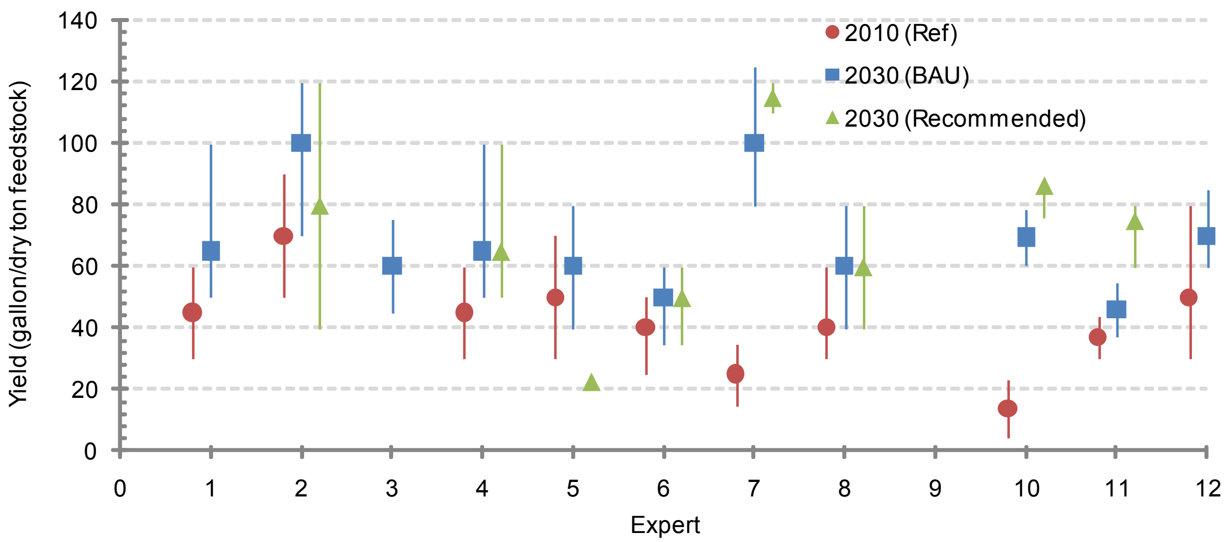


FIGURE A-10. Expert 2010 jet fuel substitute conversion yield, predicted 2030 jet fuel substitute conversion yield under business-as-usual budget and recommended spending. The plot shows the 10th, 50th, and 90th percentile estimate per each expert. Expert 9 did not provide 2010 or 2030 jet fuel substitute conversion yields.

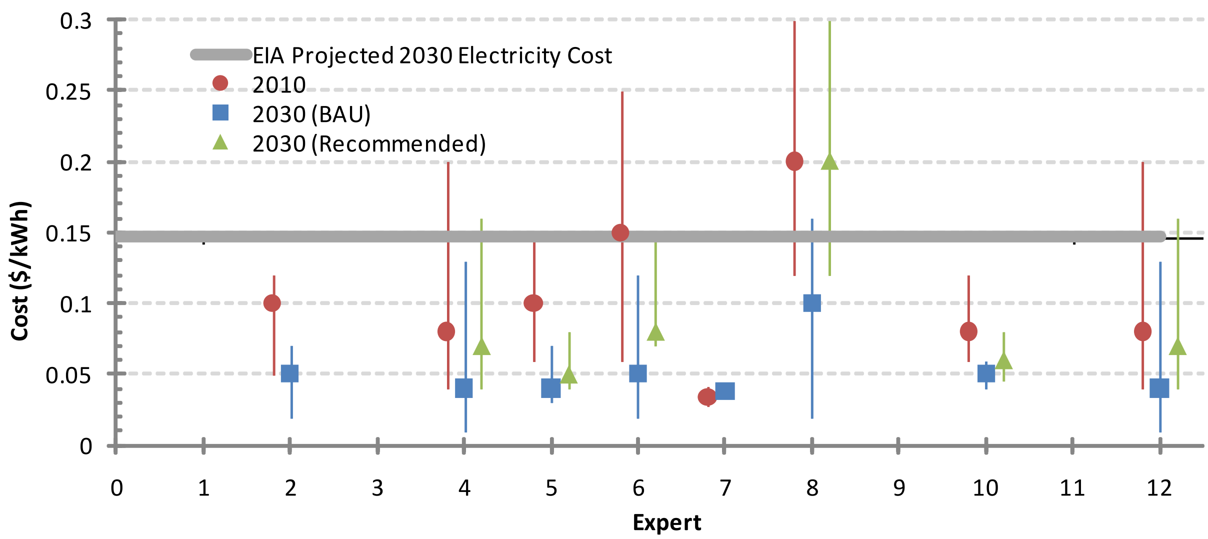


FIGURE A-11. Expert 2010 electricity production cost, predicted 2030 electricity production costs under business-as-usual budget, and 2030 electricity production cost under recommended spending. The 2030 electricity cost predicted by the EIA AEO 2010 is $0.147/kWh. The plot shows the 10th, 50th, and 90th percentile estimate per each expert. Experts 1, 3, and 9 did not provide 2010 or 2030 electricity production costs.

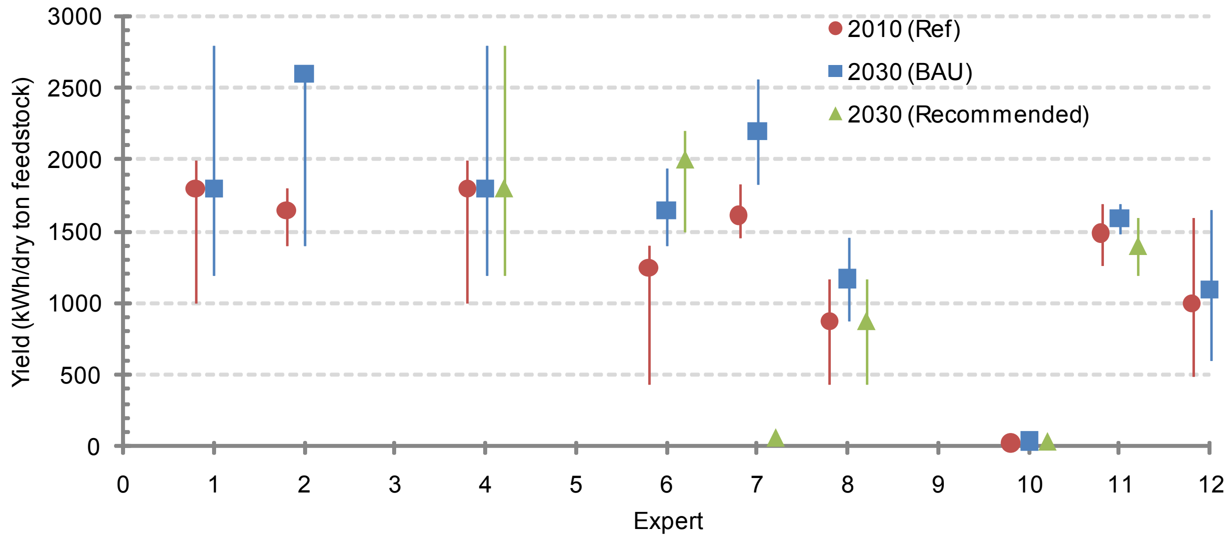


FIGURE A-12. Expert 2010 biomass-based electricity conversion yield, predicted 2030 biomass-based electricity conversion yield under business-as-usual budget and recommended budget. The plot shows the 10th, 50th, and 90th percentile estimate per each expert. Experts 3, 5, and 9 did not provide 2010 or 2030 electricity conversion yields.

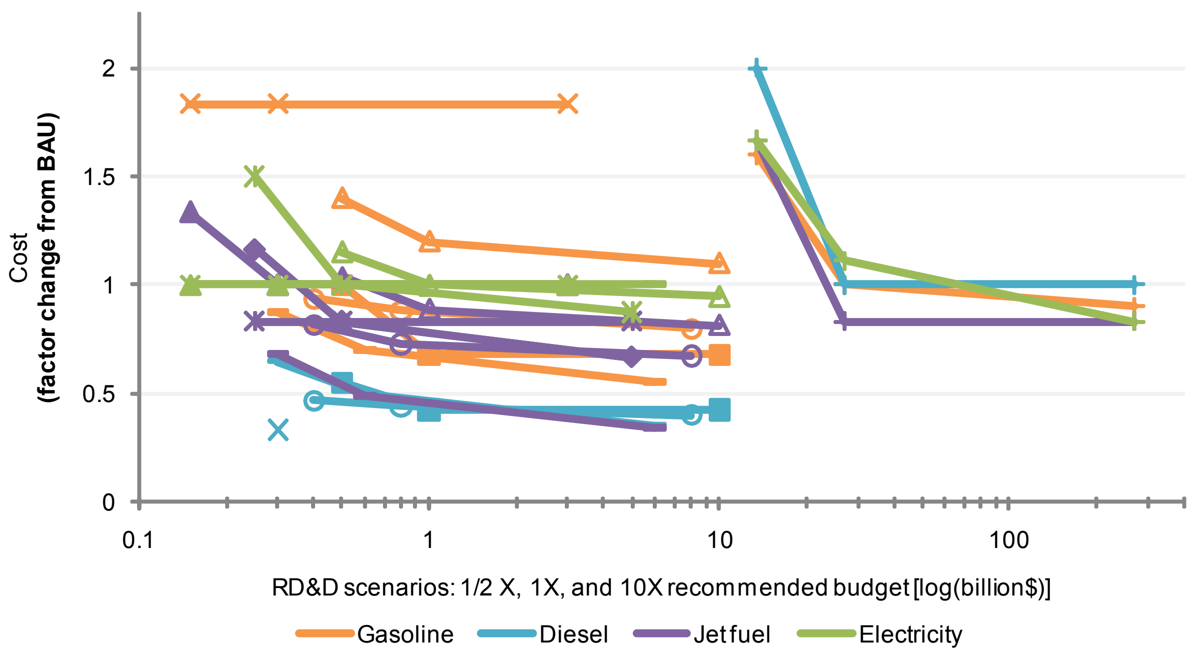
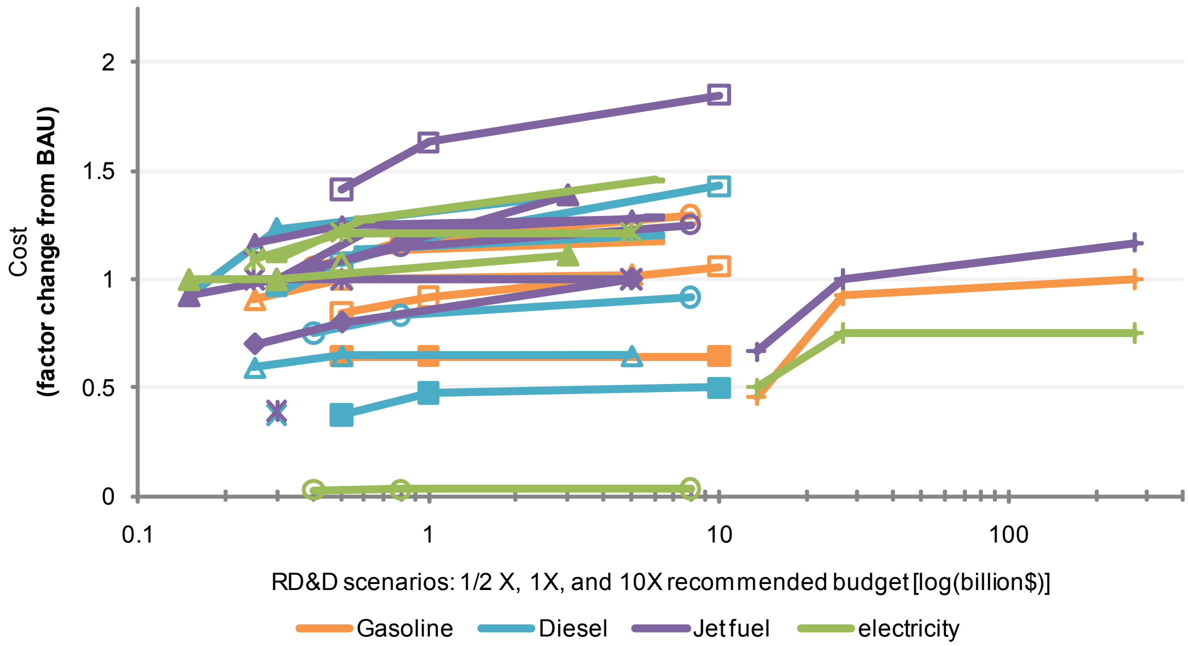


FIGURE A-13. Change in Biomass-based Fuel Cost in 2030 compared to BAU funding scenario under each expert's recommended budget, half of recommended budget, and ten times recommended budget. Some experts' responses are not included because they did not make sense, i.e. costs increase significantly rather than decline with more funding. Not all of the experts estimated production costs under their recommended budget. change in overnight capital cost against.



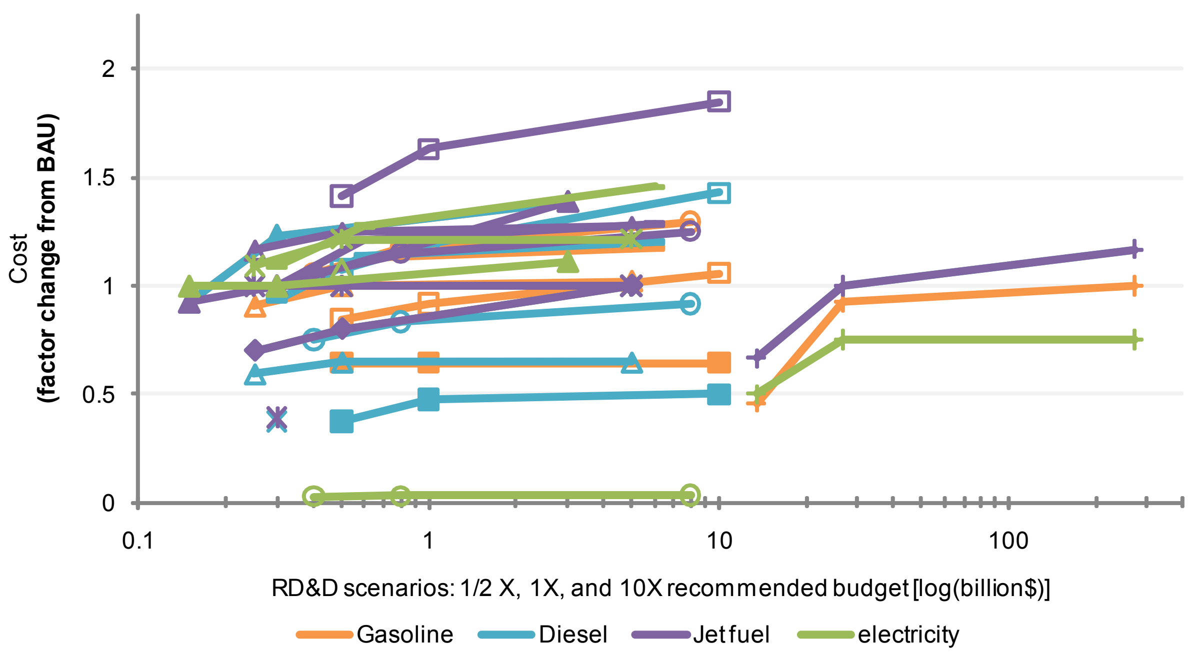


FIGURE A-14. Change in Biomass-based Fuel Yield in 2030 compared to BAU funding scenario under each expert's recommended budget, half of recommended budget, and ten times recommended budget.

duction cost range of \$0.25/gallon–\$5.00/gallon. Figures A-10 shows that the experts expect 2030 50th percentile conversion yields for biomass-based jet fuel substitutes to range from 42–200 gallon per dry ton of feedstock, and increase by 20–400% over 2010 conversion yields. If the experts' recommended budgets are implemented, 50th percentile jet fuel costs will range from \$0.25–\$5.00 per gallon in 2030.

Figures A-11 to A-12 show the electricity cost and conversion yield that experts predicted in 2030 compared to their estimates of cost and conversion yield in 2010 under business as usual funding. Figure A-11 shows that the EIA AEO 2010 projected cost of electricity generation in 2030, \$0.147/kWh, falls within the 4 experts' estimated ranges of 2030 biomass-based electricity generation cost and is greater than 5 experts' estimated ranges of 2030 biomass-based electricity generation cost. We can see that as a group the experts believe that 50th percentile electricity generation costs will decrease by 8 to 85% by 2030 if funding does not change. If funding changes as they recommend, 50th percentile biomass-based electricity generation cost is expected to range from \$0.05 - \$1.30 per kWh. Figures A-12 show that the experts expect 2030 50th percentile conversion yields for electricity to range from 40–2600 kWh per dry ton of feedstock, and increase by 7-58% over 2010 conversion yields. If experts' recommended budgets are implemented, 50th percentile expected conversion yields for biomass-based electricity range from 43–2000 kWh per dry ton of feedstock.

Figures A-13 and A-14 compare experts' business as usual and anticipated liquid fuel and electricity costs and conversion yields per their recommended budgets to identify the impact of increasing RD&D investments over the BAU scenario. While experts exhibit considerable disagreement on 2010 or 2030 BAU costs and yields (Figures A-5 to A-12), there is more consensus on their estimates of the cost reductions that can be achieved through increased federal RD&D. Most experts believed that a revamped federal RD&D program would reduce costs, but not all experts believed it would increase conversion yields. For example, Figure A-13 shows that experts expected that a \$600 million budget would result in gasoline production cost reductions of 51% to 69% over 2030 BAU costs. Experts appear more divided about production costs for diesel substitutes, jet fuel substitutes, and electricity. Experts said that a \$600 million federal RD&D budget could result in as much as a 22% increase in diesel production cost reductions to 56% decrease in production costs compared to the 2030 BAU scenario. Our results also show that experts expect the response of jet fuel production costs to federal RD&D funding changes are very uncertain—costs could increase up to 13% or decrease by 86%. Biomass-based electricity costs would increase by 7% or decrease up to 27%. Unlike the relative clustering that was found in the experts' estimates of cost reductions when compared to the BAU RD&D scenario, the expected yield improvements over the BAU RD&D scenario (Figure A-14) were evenly spread for gasoline, diesel, and jet fuel substitutes from 58% reduction to 51% increase in conversion yields if RD&D funding were increased to \$600 million. We believe that this wide range represents the uncertainty in the field when considering future conversion yields.

A.2. Energy storage

We would like to thank the participating experts (Table A-3) for generously sharing their time and expertise. We randomly assigned each a number between 1 and 25 in our results.

We asked experts to estimate cost and performance of grid-scale, greater than 30 minutes duration bulk energy storage for integration of low-carbon power generation in 2010 and in 2030 if federal funding and policy for energy storage RD&D does not change over the 20-year period, as well as in 2030 for varying levels of their recommended budget and allocation. This budget and allocation is based on how they assigned an annual budget among the technologies in Table A-4.

Name	Affiliation
Dale T. Bradshaw	National Electric Cooperative Association
Scott Brown	New Energy Capital
Nancy Clark	Sandia National Laboratory
Garth Corey	Sandia National Laboratory
Paul Denholm	National Renewable Energy Laboratory
Christopher J. Grieco	Launchpoint Innovations, LLC
Bill Gray	Velkess, Inc.
David E. Gushee	Retired from Congressional Research Service
Chad Hall	Ioxus, Inc.
Tim F. Havel	Energy Compression, Inc.
Timothy D. Heidel	MIT
Eric Ingersoll	General Compression
Matt Lazarewicz	Beacon Power Corp.
Bernard Lee	Retired president and CEO of the Institute of Gas Technology
Eric D. Lougher	Southwest Solar Technologies, Inc.
Jason Makansi	Pearl Street, Inc.
Michael J. McGill	Electricity & Air Storage Enterprises, LLC
Sekari Mtingwa	MIT
Karen D. Parysek	Praxair, Inc.
Bradford P. Roberts	S&C Electric Company, Power Quality Products Division
Samir Succar	Natural Resources Defense Council
Charles Vartanian	A123 Systems
Robert Webster	Magnum Energy
Steve Willard	PNM Resources
Chi-Jen Yang	Duke University

Table A-3. Experts who completed the elicitation about grid-scale energy storage

Energy Storage Technology		
Pumped hydro	Compressed air energy	Batteries
Flow batteries	Thermal	Fuel cells
Superconducting magnetic energy	Flywheels	Electrochemical capacitors

TABLE A-4. Technologies presented to experts

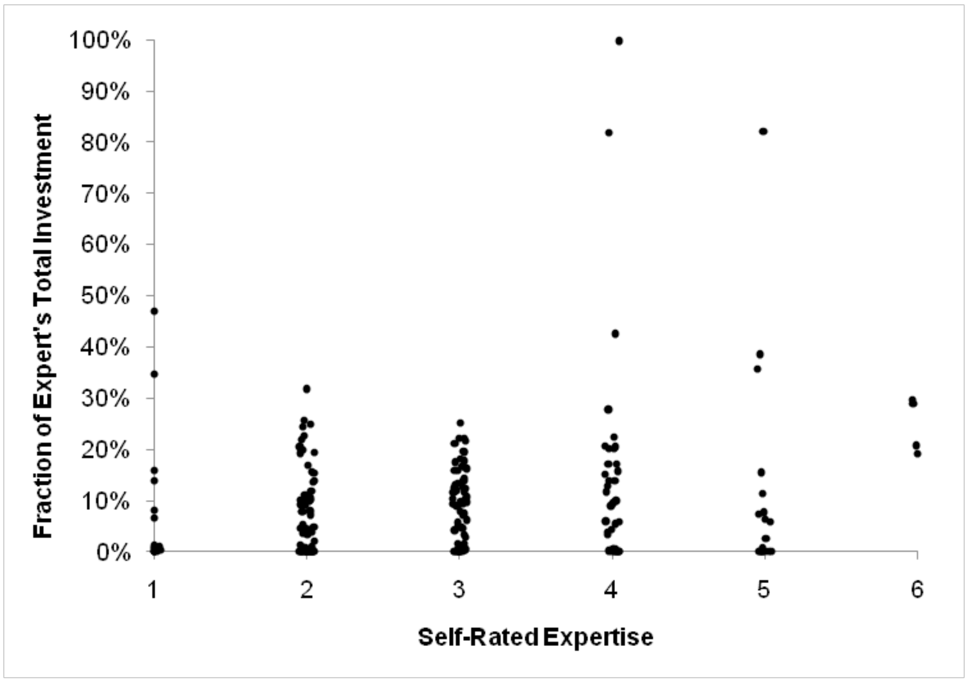


Figure A-15. Analysis of energy storage expert bias in budget allocation toward their areas of expertise. Each point corresponds to the fraction of the recommended budget that an expert devoted to a particular technology (y-axis) and the expert's self-assessment of his level of expertise in the same technology (x-axis). The increasing density of the circles shows greater number of experts with same level of expertise and budget allocation to a given technology.

We compared experts' budget recommendations against their self-assessed expertise per technology and conclude that there is insignificant bias in their budget allocations towards their areas of expertise. As shown in Figure A-15, while there were a few exceptions, experts were not biased to funding those areas in which they had high levels of expertise (4 to 6). Most experts recommended funding areas in which they had lower expertise levels.

The average annual spending recommendation among the experts is $244 million. The experts recommended a range of funding for energy storage technology basic research, applied research, experiments and field demonstration, and commercial demonstration. Experts designated the "Other" technology category in the allocation as underground modular pumped hydro, storage system, grid monitoring,

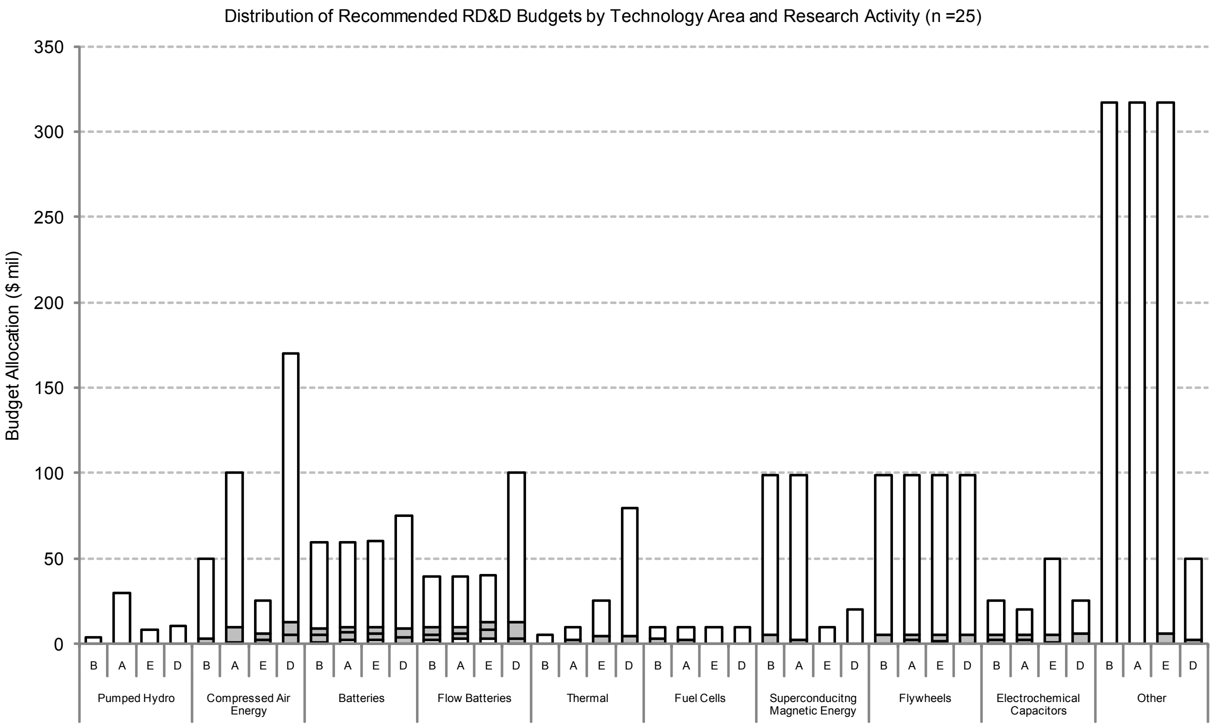


FIGURE A-16. Minimum, average, and maximum budget allocation over all experts per technology and innovation stage (million $). Hydro=pumped hydro, CAES=compressed air energy storage, Flow Batt = flow batteries, SMES = superconducting magnetic energy storage, ElCh Cap = electrochemical capacitors. Basic = basic research, Applied = applied research, ExpPilots = experiments and field pilots, C Demo = commercial demonstration. Note that we collected a sample of experts that is representative of the field rather than a "statistically representative" sample. As such, each expert's opinion is an individual viewpoint in the field. However, we chose to show an "average" of the recommended percentage allocation because the maximum and minimum are extreme in many cases; the minimum budget allocation for a given technology is 0.

enabling smart meters, CAES with heat storage, liquid air energy storage, thermistor based storage, and mechanical storage systems other those already identified in the elicitation. We show the group's recommended funding allocation as dollar and percentage allocation of the experts' budgets. Figure A-16 shows the range of absolute budget allocation among the twelve experts who participated in the survey. We plot minimum, mean, and maximum allocation amount per innovation stage and technology, as well as 25th and 75th percentiles. Figure A-17 shows the values for the mean budget allocation, by innovation stage and technology, shown in Figure A-16. Figure A-18 shows the same information as percentage of total budget. As shown in Figures A-16 and A-17, the greatest amounts of spending on a dollar basis is on "other" basic and applied research, and experiments and field demonstrations as well as CAES commercial demonstration. However, the high "other" expenditure is driven by one expert's opinion to allocate a small portion of his very large recommended budget to "other" research. We get a different answer when considering allocation on a percentage basis. As shown in Figure A-18, which present the data as a percentage of experts' budget recommendations, on average the experts thought that energy storage funding should focus on commercial demonstration of CAES and flow batteries,

	Pumped Hydro	Compressed Air Energy	Batteries	Flow Batteries	Thermal	Fuel Cells	Superconducitng Magnetic Energy	Flywheels	Electrochemical Capacitors	Other
Basic Research	0.2	4.7	8.9	6.8	0.7	1.6	6.4	6.5	4.0	14.0
Applied Research	1.6	7.7	9.5	8.3	2.0	1.6	5.6	7.7	3.7	15.4
Experiments and Pilots	0.7	4.6	9.9	10.3	3.7	1.3	0.7	8.2	5.6	16.5
Commercial Demonstration	1.3	17.6	11.0	12.0	6.1	1.3	1.1	7.0	4.8	3.7
Total	3.8	34.6	39.3	37.4	12.5	5.9	13.8	29.4	18.0	49.7

Figure A-17. Average allocation of recommended annual federal grid-level energy storage RD&D budget for 2010-2030 (million $). One expert recommended both a large total amount and a large portion for the "other" category, thus making the total for "other" in absolute terms proportionally higher than in percentage terms.

	Pumped Hydro	Compressed Air Energy	Batteries	Flow Batteries	Thermal	Fuel Cells	Superconducitn g Magnetic Energy	Flywheels	Electrochemical Capacitors	Other
Basic Research	0.2	1.8	4.5	4.0	0.5	1.3	1.9	1.5	2.3	1.1
Applied Research	0.7	3.7	4.9	4.9	1.4	1.1	1.1	2.5	2.4	1.7
Experiments and Pilots	0.7	3.7	4.2	7.1	2.0	0.6	0.4	2.2	2.3	2.4
Commercial Demonstration	1.4	8.3	4.6	7.8	1.6	0.7	0.6	1.9	2.1	1.7
Total	3.0	17.5	18.2	23.9	5.5	3.7	4.0	8.1	9.2	7.0

Figure A-18. Average allocation of recommended federal grid-level energy storage RD&D budget for 2010-2030 (percent)

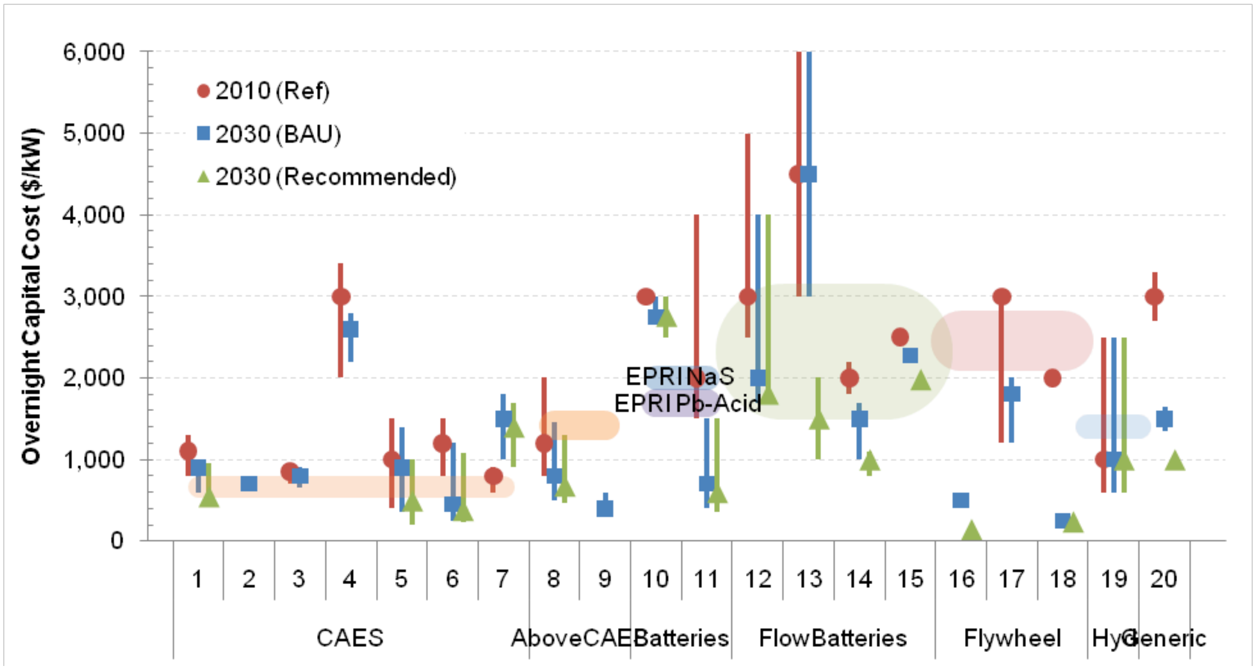


Figure A-19. Median, 10th percentile, and 90th percentile overnight capital cost estimates in 2010 and 2030 by expert and technology under business-as-usual federal energy storage RD&D funding and experts' recommended funding, compared with EPRI* estimates in colored bubbles. One expert provided balance-of-plant costs for thermal energy storage, which are not shown here. CAES technologies include diabatic, adiabatic, and isothermal air storage. EPRI CAES, batteries, and pumped hydro costs are current costs. EPRI aboveground CAES (Above-CAES), flow batteries, and flywheels costs are projected costs.

experiments and pilots for flow batteries, and applied research for batteries and flow batteries.

Experts provided judgment on energy storage cost by specific technologies available in 2010 and expected to improve by 2030. As Figure A-19 shows, the lowest median cost energy technology will be available at less than $1/W. EPRI estimated energy storage costs by technology are within the same order of magnitude as the experts' predicted costs. The EPRI CAES, batteries, and pumped hydro costs that are based on current cost data are within the experts' estimated range. However, EPRI aboveground CAES, flow battery, and flywheel costs are projected and agree less with the experts' judgment. EPRI aboveground CAES costs are greater than or at the high end of the experts' estimated ranges. EPRI flywheel costs are greater than the experts' estimated ranges. Experts predict between 6-88% reduction in 50th percentile grid-level energy storage costs by 2030 under business as usual conditions, and one expert predicting an increase in costs. Figure A-19 also compares experts' business as usual and anticipated energy storage costs per their recommended budgets to identify the impact of increasing RD&D investments over the BAU scenario. Experts believe that with increased funding, overnight capital costs

* R.B. Schainker, "Emerging Technologies to Increase the Penetration and Availability of Renewables: Energy Storage – Executive Summary," July 2008.

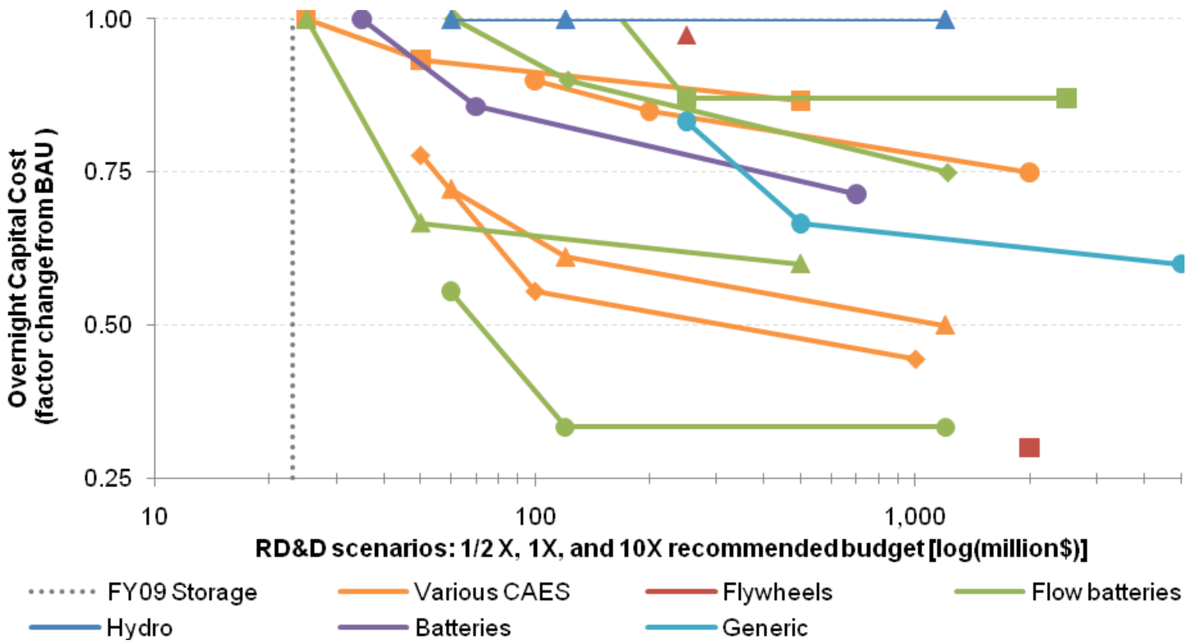


FIGURE A-20. Change in grid-level energy storage cost in 2030 compared to BAU funding scenario under each expert's recommended budget, half of recommended budget, and ten times recommended budget. CAES technology includes CAES with concentrating solar power, adiabatic CAES, aboveground CAES using liquid air, CAES in a reservoir with natural gas as a fuel, and CAES in a salt reservoir with no fuel required. Batteries include Li-ion and NaS. The gray dotted line refers to DOE's FY 2009 budget for all energy storage technologies, $23 million.

will decrease over the business as usual. The exception is the pumped hydro expert who did not expect any change in overnight capital costs over his expected BAU overnight capital cost regardless of any additional funding. This is also shown in Figure A-20 where cost reductions in 2030 for specific storage technologies are plotted against experts' recommended budget for that technology (not the experts' total recommended budget for energy storage).

Most importantly, however, the experts' answers provide insight into the range of cost reduction to be gained for spending the experts' average recommended budget of $240 million. Four experts provided estimates about the future cost of CAES, and four experts provided estimates about future flow battery costs. The CAES experts expected CAES overnight capital costs could be reduced by 10-46% by spending $240 million on energy storage RD&D. For this budget, flow battery experts estimated that overnight capital costs would be reduced by 12-67%. Generic energy storage technology overnight capital costs would decrease up to 16% over BAU costs and battery overnight capital costs up to 18% over BAU.

A.3. Nuclear technology

We would like to thank the participating experts (Table A-5) for generously sharing their time and expertise. We randomly assigned each a number between 1 and 32 in our results.

We asked experts to estimate cost and performance of electricity producing Generation III/III+ plants, Generation IV plants, and small to medium (<300 MWe) reactors in 2010 and in 2030 if federal funding and policy for nuclear technology RD&D does not change over the 20-year period, as well as in 2030 for

Name	Affiliation
John F. Ahearne	NRC, NAS nuclear power, Sigma XI
Joonhong Ahn	University of California at Berkeley
Edward D. Arthur	Advanced Reactor Concepts
Sydney J. Ball	Oak Ridge National Laboratory
Ashok S. Bhatagnar	Tennessee Valley Authority
Bob Budnitz	Lawrence Berkeley National Laboratory
Douglas M. Chapin	MPR Associates
Michael Corradini	University of Wisconsin
B. John Garrick	U.S. Nuclear Waste Technical Review Board
Michael Warren Golay	Massachusetts Institute of Technology
Eugene S. Grecheck	Dominion Energy, Inc.
Pavel Hejzlar	TerraPower USA
J. Stephen Herring	Idaho National Laboratory
Thomas Herman Isaacs	Stanford University and Lawrence Livermore National Laboratory
Kazuyoshi Kataoka	Toshiba
Andrew C. Klein	Oregon State University
Milton Levenson	Retired (previously at ORNL, Bechtel, and EPRI)
Regis A. Matzie	RAMatzie Nuclear Technology Consulting, LLC (previously at Westinghouse)
Andrew Orrell	Sandia National Laboratory
Kenneth Lee Peddicord	Texas A&M University
Per F. Peterson	University of California at Berkeley
Paul Pickard	Sandia National Laboratory
Burton Richter	Stanford University
Geoffrey Rothwell	Stanford University
Pradip Saha	Wilmington, North Carolina
Craig F. Smith	Livermore/Monterey Naval Post Graduate School
Finis H. Southworth	Areva
Temitope A. Taiwo	Argonne National Laboratory
Neil Emmanuel Todreas	Massachusetts Institute of Technology
Edward G. Wallace	Pebble Bed Modular Reactor (Pty) Ltd.

Table A-5. Experts who completed the elicitation about nuclear technology varying levels of their recommended budget and allocation. This budget and allocation is based on how they assigned an annual budget among the technologies in Table A-6.

We compared experts' budget recommendations against their self-assessed expertise per technology and conclude that there is insignificant bias in their budget allocations towards their areas of expertise. As shown in Figure A-21, experts were slightly biased against spending money in areas where they had little to no expertise (level 1 expertise). However, for medium (2 and 3) to high (4 to 6) levels of expertise, experts appear to have little bias. They award up to 40% of their recommended RD&D budgets for technologies and products in which they have medium to high levels of expertise.

Specific reactor systems	Cross-cutting areas
Gas-cooled fast reactor system (GFR)	Fuel cycle
Sodium-cooled fast reactor system (SFR)	Fuels and materials
Lead-cooled fast reactor (LFR)	Risk and safety
Supercritical-water-cooled reactor system (SCWR)	Economics
Molten salt reactor system (MSR)	Proliferation resistance and physical protection
Very-high-temperature reactor system (VHTR)	Non-power products (e.g. H2)
Small-medium factory-built (battery) reactors (SMR)	

Table A-6. Technologies presented to the experts

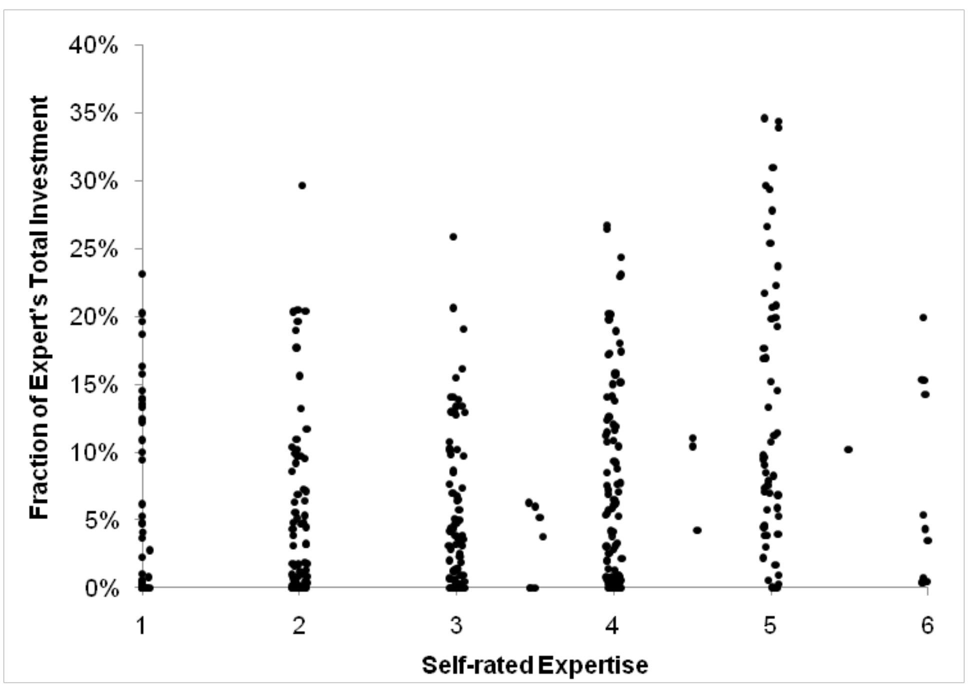


FIGURE A-21. Analysis of nuclear technology expert bias in budget allocation toward their areas of expertise. Each point corresponds to the fraction of the recommended budget that an expert devoted to a particular technology (y-axis) and the expert's self-assessment of his level of expertise in the same technology (x-axis). The increasing density of the circles shows greater number of experts with same level of expertise and budget allocation to a given technology.

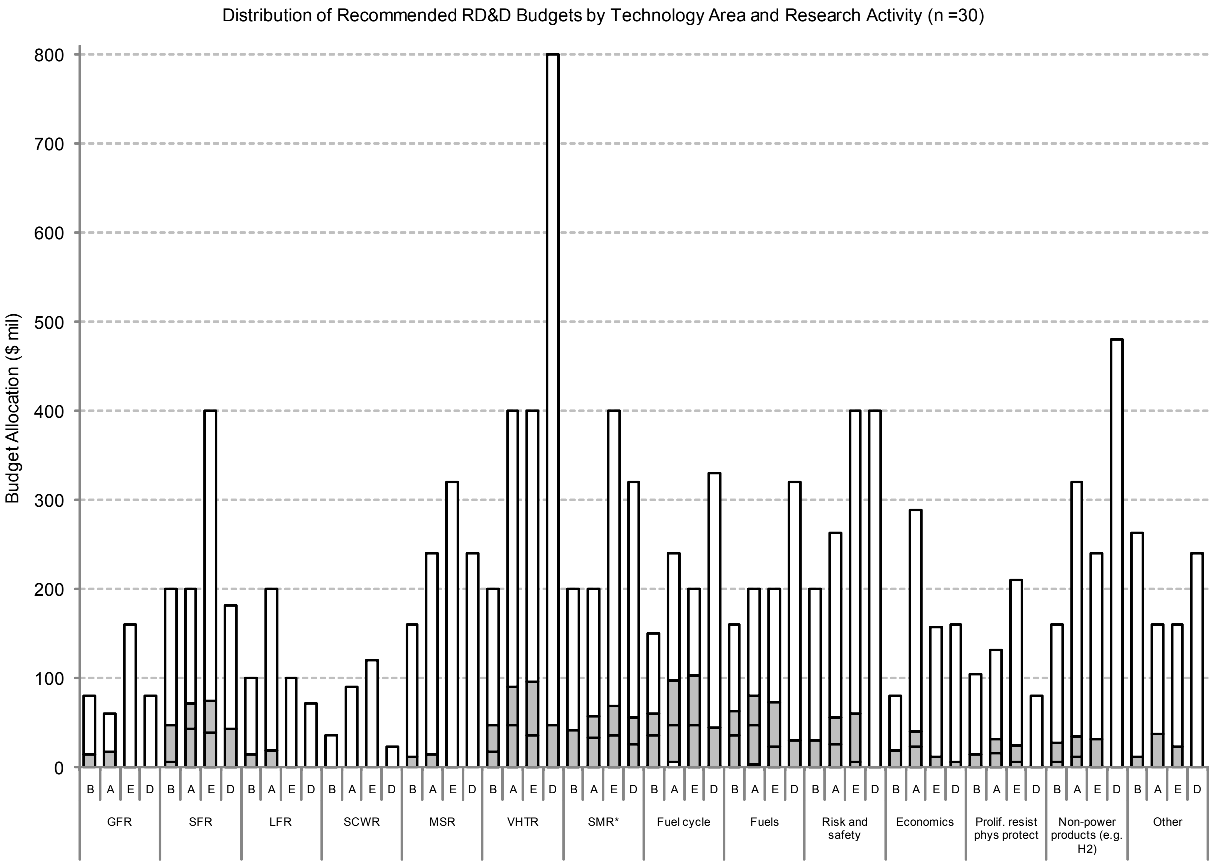


FIGURE A-22. Minimum, average, and maximum budget allocation over all experts per technology and innovation stage (million $). GFR=Gas-cooled fast reactor system, SFR=Sodium-cooled fast reactor system, LFR = Lead-cooled fast reactor system, SCWR = Supercritical-water-cooled reactor system, MSR = Molten salt reactor system, VHTR = Very-high-temperature reactor system, SMR = Small-medium factory-built (battery) reactors. Fuels = Fuels and materials, Risk Safe = Risk and Safety, Econ = Economics, Prot = Proliferation resistance and physical protection, Non-pow = Non-power products (e.g. H_2). Basic = basic research, Applied = applied research, ExpPilots = experiments and field pilots, C Demo = commercial demonstration. Note that we collected a sample of experts that is representative of the field rather than a "statistically representative" sample. As such, each expert's opinion is an individual viewpoint in the field. However, we chose to show an "average" of the recommended percentage allocation because the maximum and minimum are extreme in many cases; the minimum budget allocation for a given technology is 0.

The average annual spending recommendation among the experts is $2 billion. The experts recommended a range of funding for nuclear power technology basic research, applied research, experiments and field demonstration and commercial demonstration. Experts designated the "Other" category to myriad issues including licensing and regulatory simplification, waste, geological disposal, supercritical CO_2 power cycle, informatic technologies, and fusion. We show the group's recommended funding allocation as dollar and percentage allocation of the experts' budgets. Figure A-22 shows the range of absolute budget allocation among the 32 experts who participated in the survey. We plot minimum, mean, and maximum allocation amount per innovation stage and technology or research area, as well as the 25th and 75th percentiles. Figure A-23 shows the values for the mean budget allocation, by innovation stage and technology, shown in Figure A-22. Figure A-24 shows the same information as percent-

	Specific reactor systems						Cross-cutting areas							Others
	GFR	SFR	LFR	SCWR	MSR	VHTR	SMR*	Fuel cycle	Fuels	Risk and safety	Economics	Prolif. resist phys protect	Non-power products (e.g. H2)	Other
Basic Research	12.0	39.3	15.8	4.7	15.3	42.4	28.4	50.8	47.7	29.5	13.0	18.1	25.9	24.1
Applied Research	12.5	57.7	20.7	5.0	21.1	71.1	44.1	76.7	60.7	54.3	42.6	31.3	36.7	26.0
Experiments and Pilots	13.2	71.1	16.2	5.9	20.3	81.7	59.7	68.8	49.9	51.0	13.5	29.0	32.1	23.1
Commercial Demonstration	8.7	48.1	5.5	1.1	9.5	76.3	49.0	46.4	28.4	22.9	15.7	10.9	25.5	22.3
Total	46.4	216.2	58.2	16.6	66.1	271.5	181.1	242.7	186.8	157.9	84.8	89.3	120.3	95.5

FIGURE A-23. Average allocation of recommended annual federal nuclear RD&D budget for 2010-2030 (million $)

	Specific reactor systems						Cross-cutting areas							Others
	GFR	SFR	LFR	SCWR	MSR	VHTR	SMR*	Fuel cycle	Fuels	Risk and safety	Economics	Prolif. resist phys protect	Non-power products (e.g. H2)	Other
Basic Research	0.8	2.3	1.0	0.4	0.7	2.1	1.5	3.0	2.8	1.4	0.7	0.9	1.5	1.5
Applied Research	0.8	3.5	1.2	0.3	0.9	3.6	2.4	4.4	3.7	2.8	2.3	1.8	1.3	1.6
Experiments and Pilots	0.9	4.5	1.0	0.3	0.7	4.1	3.3	4.3	2.8	2.2	0.8	1.7	1.2	1.3
Commercial Demonstration	0.6	3.5	0.4	0.1	0.2	3.5	3.0	2.3	1.5	0.8	0.8	1.6	0.0	1.2
Total	3.1	13.8	3.5	1.1	2.5	13.4	10.1	14.0	10.7	7.2	4.6	5.2	5.1	5.6

FIGURE A-24. Average allocation of recommended annual federal nuclear RD&D budget for 2010-2030 (percentage of total)

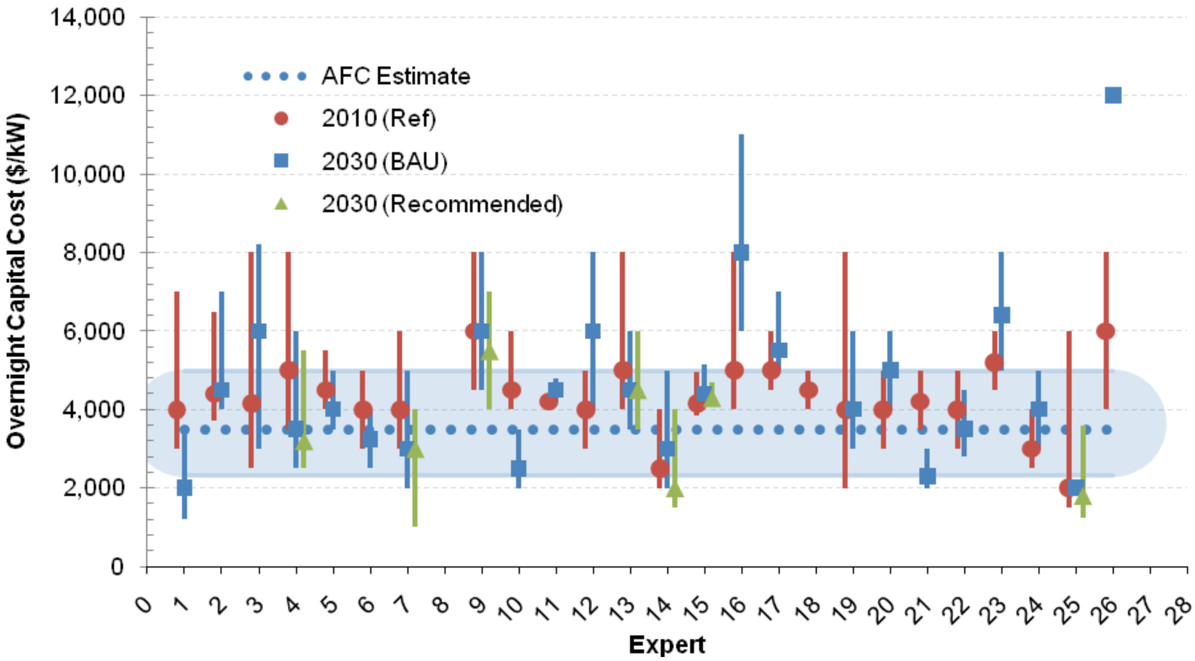


FIGURE A-25. Median, 10th percentile, and 90th percentile 1,000 MW Generation III/III+ overnight capital cost estimates in 2010, and 2030 under business-as-usual federal nuclear RD&D funding and experts' recommended RD&D funding compared with the DOE* best estimate of LWR overnight capital cost ($2.3/W) in 2025.

age of total budget. As shown in Figures A-23 and A-24, the greatest amounts of spending on a dollar basis were allocated to VHTR, fuel cycle, SFR, and SMR. When looking at how experts allocated their spending on a percentage basis (Figure A-24) we see that they emphasized fuel cycle experiments and pilots, applied fuel cycle research, all VHTR innovation stages except for basic research, and SFR pilot projects and demonstration.

Experts provided judgment on nuclear power cost by specific technologies available in 2010 and expected to improve by 2030. We asked experts to provide 2010 estimates for Generation III/III+ technology, but because Generation IV and modular reactor technologies are considered nascent we did not ask for 2010 cost experts for them. As Figures A-25 shows, the experts' median estimates of overnight capital costs for 1,000 MW Generation III/III+ plants range from $2/W - $12/W, such that the DOE best estimate of 2025 LWR overnight capital costs ($2.3/W) falls on the low end of the experts' best estimates. The experts predict that median 2030 Generation III/III+ overnight capital costs will be anywhere from half to two 2010 median Generation III/III+ overnight capital costs. As previously mentioned, we asked experts to provide only their future overnight capital cost estimates for Generation IV and modular re-

* Shropshire, D.C., Williams, K.A., Hoffman, E.A., Smith, J.D., Hebditch, D.J., Jacobson, J.J., Morton, J.D., Phillips, A.M., and Taylor, J.P. (2009). "Advanced Fuel Cycle Economic Analysis of Symbiotic Light-Water Reactor and Fast Burner Reactor Systems." Document INL/EXT-09-15254. Prepared for the U.S. Department of Energy Office of Nuclear Energy. January.

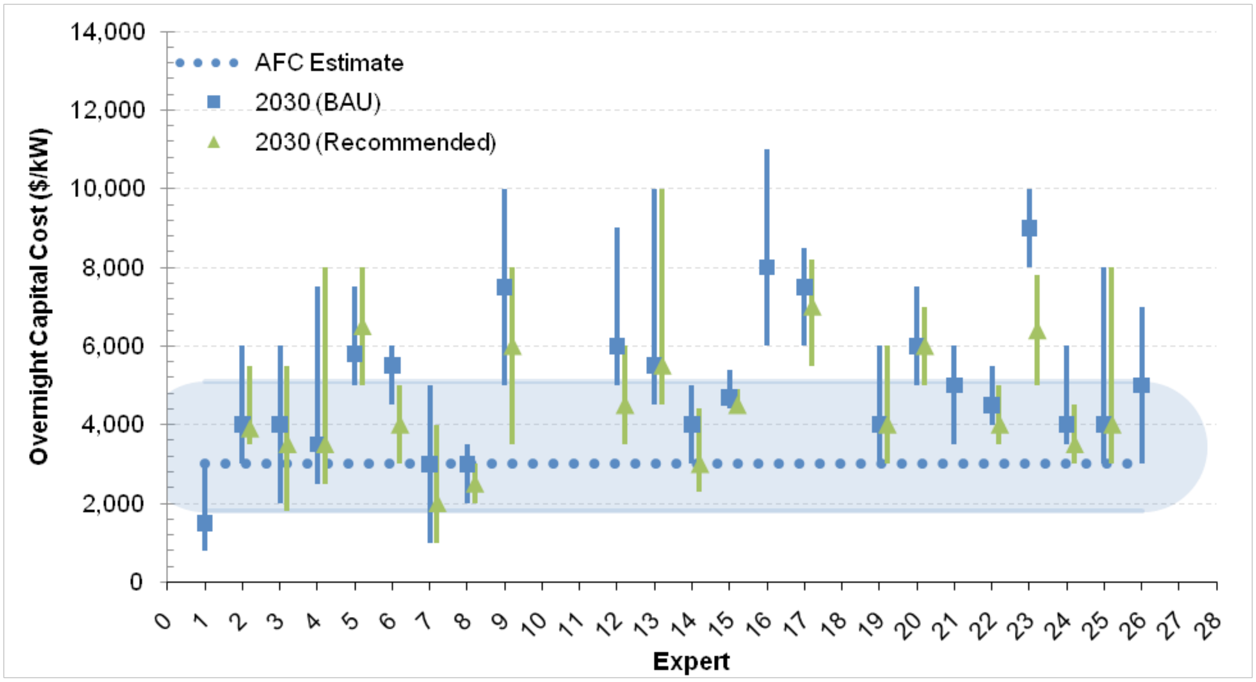


FIGURE A-26. Median, 10th percentile, and 90th percentile 1 GWe Generation IV overnight capital cost estimates in 2030 by expert under business-as-usual federal nuclear RD&D funding and recommended RD&D funding, compared to DOE2 best estimate of fast reactor costs ($3/W) in 2025. Experts 3, 7, 10, 13, 14, 15, 17, and 30 did not provide overnight capital cost estimates.

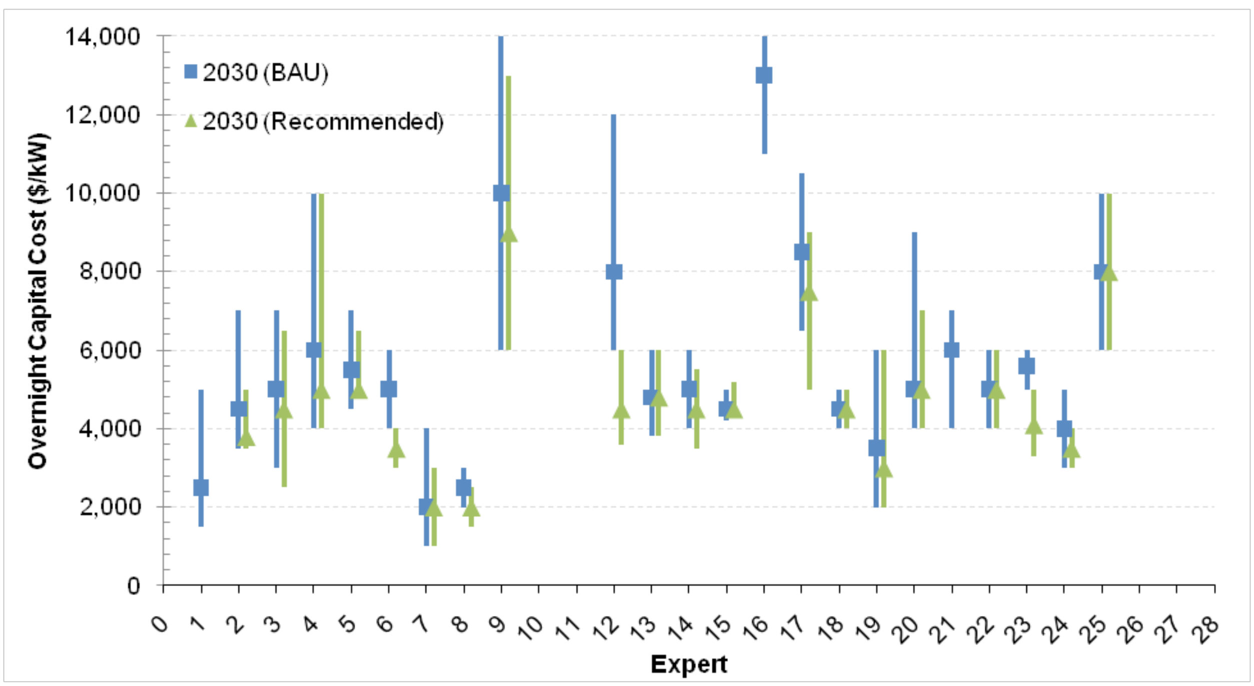


Figure A-27. Median, 10th percentile, and 90th percentile modular reactor (<300 MWe) overnight capital cost estimates in 2030 by expert under business-as-usual federal nuclear RD&D funding and recommended RD&D funding. Experts 3, 7, 10, 14, 15, 17, 30, and 32 did not provide overnight capital cost estimates.

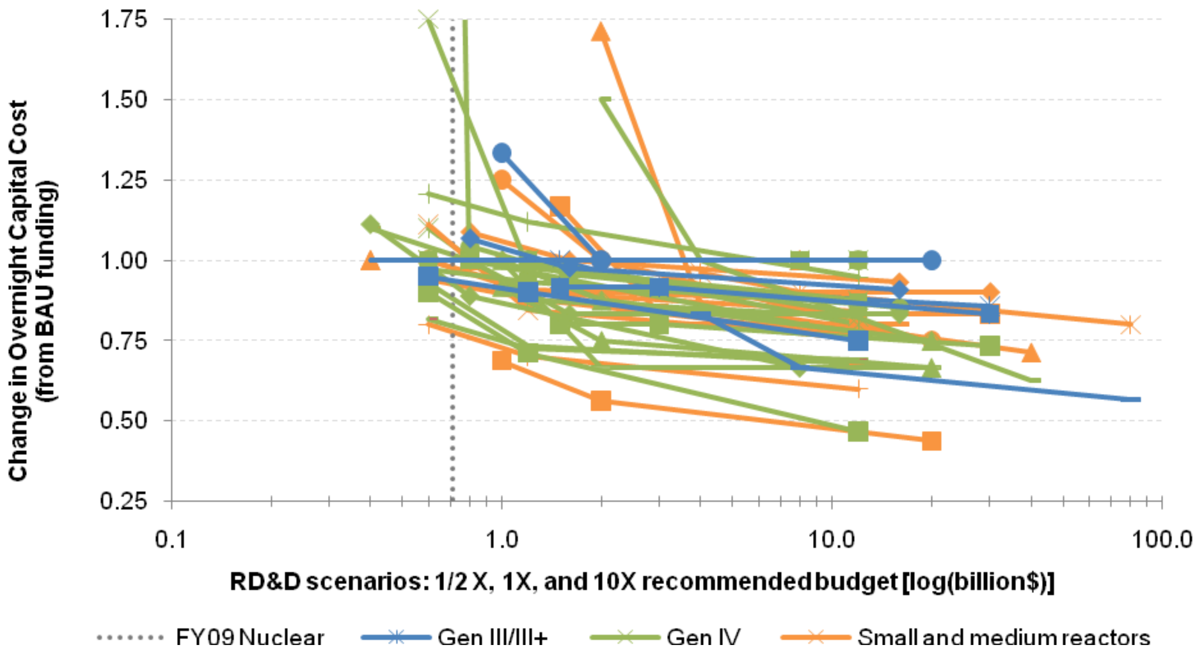


FIGURE A-28. Change in nuclear technology cost (1 GWe Generation III/III+ plant, 1 GWe Generation IV plant, <300 MWe modular reactor) in 2030 compared to BAU funding scenario under each expert's recommended budget, half of recommended budget, and ten times recommended budget. The gray dotted line refers to DOE's FY 2009 budget for all nuclear technologies, $711 million.

actors. In Figure A-26, the experts best estimates of 2030 1 GWe Generation IV overnight capital costs range from $1.5-$9/W, which is comparable to the DOE best estimate of 2025 fast reactor overnight capital cost ($3/W). In Figure A-27, the experts best estimates of 2030 modular reactor (<300 MWe) overnight capital costs range from $2.5-$13/W.

Figure A-28 compares experts' business as usual and anticipated nuclear technology costs per their recommended budgets to identify the impact of increasing RD&D investments over the BAU scenario. Experts appear to believe that with increased funding, overnight capital costs will decrease over the business as usual. Recall that experts recommended funding amounts and allocation. The combination of applying their allocation and budget to technology RD&D will change overnight capital costs from the expected BAU overnight capital cost. Some experts appear to believe in a de minimus spending amount such that, although their recommended allocation were followed but without this de minimus spending, overnight capital costs would increase over the BAU. For example, one expert who provided estimates of Generation III/III+ plant overnight capital costs expected costs to increase by 6% over the BAU, if his budget allocation were followed and $800 million spent on nuclear technology RD&D. The same expert believed that overnight capital costs would be reduced by 3% if spending were $1.6 billion, and by up to 10% if $16 billion were spent.

The experts' answers provide insight into the range of cost reductions to be gained for additional spending. Six experts provided estimates about the future overnight capital costs of 1,000 MW Generation III/III+ plants under the revised RD&D funding scenarios (the remaining experts did not think that federal RD&D funding beyond the BAU scenario would have any impact on future cost of Gen III/III+ reactors), while 19 experts estimated overnight capital costs of 1 GWe Generation IV plants, and 20 experts estimated overnight capital costs of <300 MWe small and medium factory-built reactors. The Generation III+ experts expected that for spending the average recommended $1.8 billion budget, the median (50th percentile) overnight capital costs in 2030 could decrease by up to 24% when compared with the BAU funding scenario. Experts who provided cost estimates for Generation IV reactors in 2030 believed that RD&D investments in nuclear energy of $1.8 billion could decrease overnight capital costs in 2030 also by 24% when compared with the BAU funding scenario . Finally, the experts believed spending $1.8 billion would either increase small reactor overnight capital costs up to 4% or decrease them by as much as 38% over the BAU.

A.4. Fossil energy technology

We would like to thank the participating experts (Table A-7) for generously sharing their time and expertise. We randomly assigned each a number between 1 and 13 in our results.

We asked experts to estimate cost and performance of fossil powered electricity generation with and without carbon capture and storage (CCS) in 2010 and in 2030 if federal funding and policy for energy storage RD&D does not change over the 20-year period, as well as in 2030 for varying levels of their recommended budget and allocation. This budget and allocation is based on how they assigned an annual budget among the technologies in Table A-8.

We compared experts' budget recommendations against their self-assessed expertise per technology and conclude that there is insignificant bias in their budget allocations towards their areas of expertise. As shown in Figure A-29, experts were biased against spending money in areas where they had little to no expertise (0 and 1). However, for medium (2 and 3) to high (4 to 6) levels of expertise, experts appear to have little bias. They award up to 40% of their recommended RD&D budgets for technologies and products in which they have medium to high levels of expertise.

The average annual spending recommendation among the experts is $2.3 billion. The experts emphasized commercial demonstration. On average, they allocated 40% of the total fossil RD&D budget to this purpose (the maximum and minimum allocated to demonstrations were 80% and 15%, respectively). Within commercial demonstration, experts focused on commercial demonstrations of IGCC, oxy-fired combustion, and retrofitting existing plants with CCS with chemical looping combustion and

Name	Affiliation
Janos Beer	Massachusetts Institute of Technology
Jay Braitsch	U.S. Department of Energy
Joe Chaisson	Clean Air Task Force
Doug Cortez	Hensley Energy Consulting LLC
James Dooley	Pacific Northwest National Laboratory Joint Global Climate Research Institute
Jeffrey Eppink	Enegis, LLC
Manoj Guha	Energy & Environmental Service International
Reginald Mitchell	Stanford University
Stephen Moorman	Babcock & Wilcox
Gary Rochelle	University of Texas at Austin
Joseph Smith	Idaho National Laboratory
Gary Stiegel	National Energy Technology Laboratory
Jost Wendt	University of Utah

TABLE A-7. Experts who completed the elicitation about fossil energy technology

Capture technologies	Chemical absorption Physical absorption Adsorption Membranes
Power from coal	Pulverized fluidized bed coal combustion Integrated gasification coal combustion Oxy-fired combustion Underground coal gasification Chemical looping combustion
Power from natural gas	Advanced turbines (combined cycle)
Resource development	Fossil resource assessment and extraction technology
Cross-cutting research areas	Non-power products (e.g., H2, chemicals, heat, refinery inputs) Fuel cell Retrofitting existing plants for CCS Sensors and controls Non-CO2 environmental control

TABLE A-8. Technologies presented to the experts

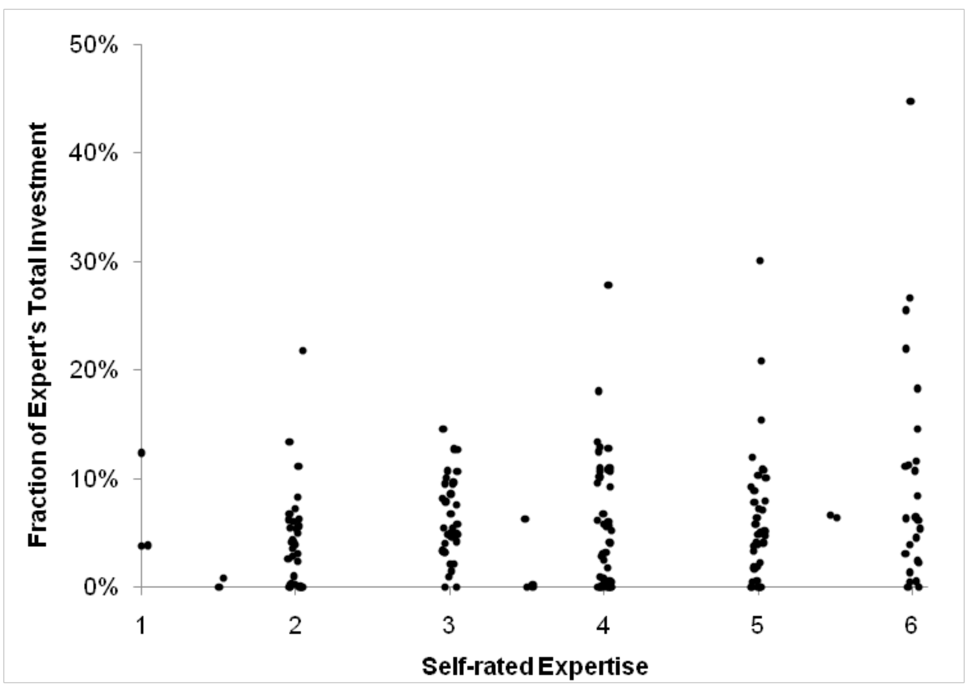


FIGURE A-29. Analysis of fossil technology expert bias in budget allocation toward their areas of expertise. Each point corresponds to the fraction of the recommended budget that an expert devoted to a particular technology (y-axis) and the expert's self-assessment of his level of expertise in the same technology (x-axis). The increasing darkness of the circles shows greater number of experts with same level of expertise and budget allocation to a given technology.

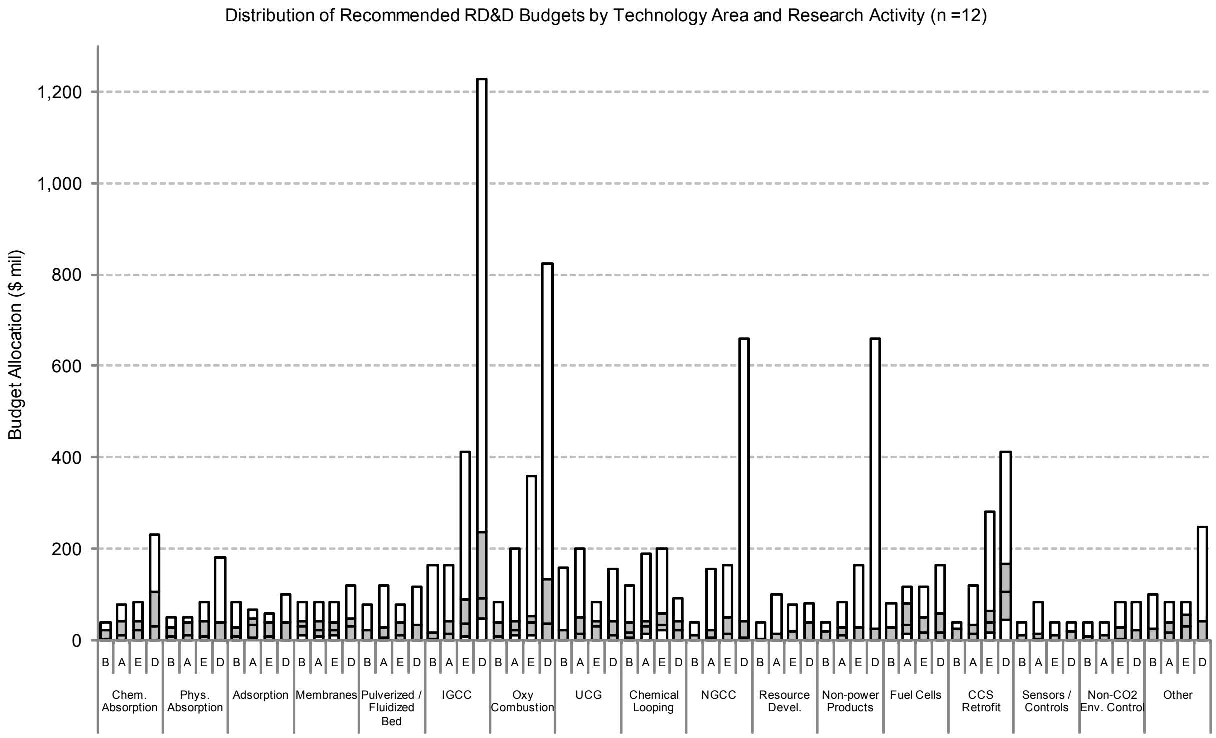


Figure A-30 Minimum, average, and maximum budget allocation over all experts per technology and innovation stage (million $). B = basic research, A = applied research, E = experiments and field demonstrations, D = Commercial-scale demonstration. The minimum is the minimum percentage of the budget that an expert dedicated to a particular technology and stage; the mean is the average percentage of the budget allocated by all experts to a particular technology area and innovation stage, and the maximum is the maximum percentage of the budget that an expert allocated to a particular technology and stage. Note that we collected a sample of experts that is representative of the field rather than a "statistically representative" sample. As such, each expert's opinion is an individual viewpoint in the field. However, we chose to show an "average" of the recommended percentage allocation because the maximum and minimum are extreme in many cases; the minimum budget allocation for a given technology is 0% in all cases but one: applied research in chemical looping.

membrane technology. The top technologies recommended by experts are IGCC and the enabling technologies for post-combustion/oxy-fired combustion capture (chemical absorption, physical absorption, adsorption, membranes, oxy-fired combustion, and retrofitting existing plants). Figure A-30 shows the range of absolute budget allocation among the 32 experts who participated in the survey. We plot minimum, mean, and maximum allocation amount per innovation stage and technology or research area, as well as the 25th and 75th percentiles. Figure A-31 shows the values for the mean budget allocation, by innovation stage and technology, shown in Figure A-30. Figure A-32 shows the same information as percentage of total budget.

	Capture Technologies				Coal Power					Gas Power	Res. Devel.	Cross-Cutting Research Areas					Others
	Chem. Absorption	Phys. Absorption	Adsorption	Membranes	Pulverized / Fluidized Bed	IGCC	Oxy Combustion	UCG	Chemical Looping	NGCC	Resource Devel.	Non-power Products	Fuel Cells	CCS Retrofit	Sensors / Controls	Non-CO2 Env. Control	Other
Basic Research	0.5	0.9	0.6	1.5	0.5	0.7	0.7	0.8	1.3	0.3	0.3	0.4	0.6	0.6	0.3	0.5	1.2
Applied Research	1.3	1.2	1.5	1.5	0.9	1.6	1.7	1.2	2.3	0.8	0.8	0.8	1.8	1.3	0.6	0.6	1.1
Experiments and Pilots	1.3	0.9	1.0	1.4	1.1	2.6	2.4	1.3	2.5	1.3	0.7	0.9	1.4	3.1	0.6	0.8	1.5
Commercial Demonstration	5.2	1.4	1.0	1.6	1.2	8.3	4.9	1.2	2.9	1.6	0.8	1.5	1.8	6.7	0.6	0.7	1.2
Total	8.3	4.4	4.1	6.0	3.7	13.1	9.7	4.4	8.9	4.0	2.5	3.7	5.7	11.7	2.1	2.7	5.0

FIGURE A-32. Average allocation of recommended annual federal fossil energy RD&D budget for 2010-2030 (percentage of total)

	Capture Technologies				Coal Power					Gas Power	Res. Devel.	Cross-Cutting Research Areas					Others
	Chem. Absorption	Phys. Absorption	Adsorption	Membranes	Pulverized / Fluidized Bed	IGCC	Oxy Combustion	UCG	Chemical Looping	NGCC	Resource Devel.	Non-power Products	Fuel Cells	CCS Retrofit	Sensors / Controls	Non-CO2 Env. Control	Other
Basic Research	11.6	15.8	18.5	32.6	14.4	21.5	20.1	21.2	26.5	7.0	6.2	8.8	16.2	11.6	6.7	9.4	21.0
Applied Research	22.3	18.7	25.3	28.5	26.8	36.4	41.0	38.0	50.1	25.3	17.8	19.0	45.8	24.9	14.6	8.1	23.9
Experiments and Pilots	28.6	25.7	20.5	30.1	22.8	73.3	67.2	30.9	50.2	36.5	16.5	24.2	34.1	59.1	8.5	16.8	33.4
Commercial Demonstration	70.4	29.5	20.8	34.7	25.6	220.9	167.0	31.5	28.6	75.5	18.3	63.7	44.2	144.8	8.8	15.1	41.6
Total	132.9	89.6	85.1	125.9	89.6	352.1	295.3	121.5	155.4	144.3	58.7	115.5	140.3	240.3	38.5	49.4	119.8

FIGURE A-31. Average allocation of recommended annual federal fossil energy RD&D budget for 2010-2030 (million $)

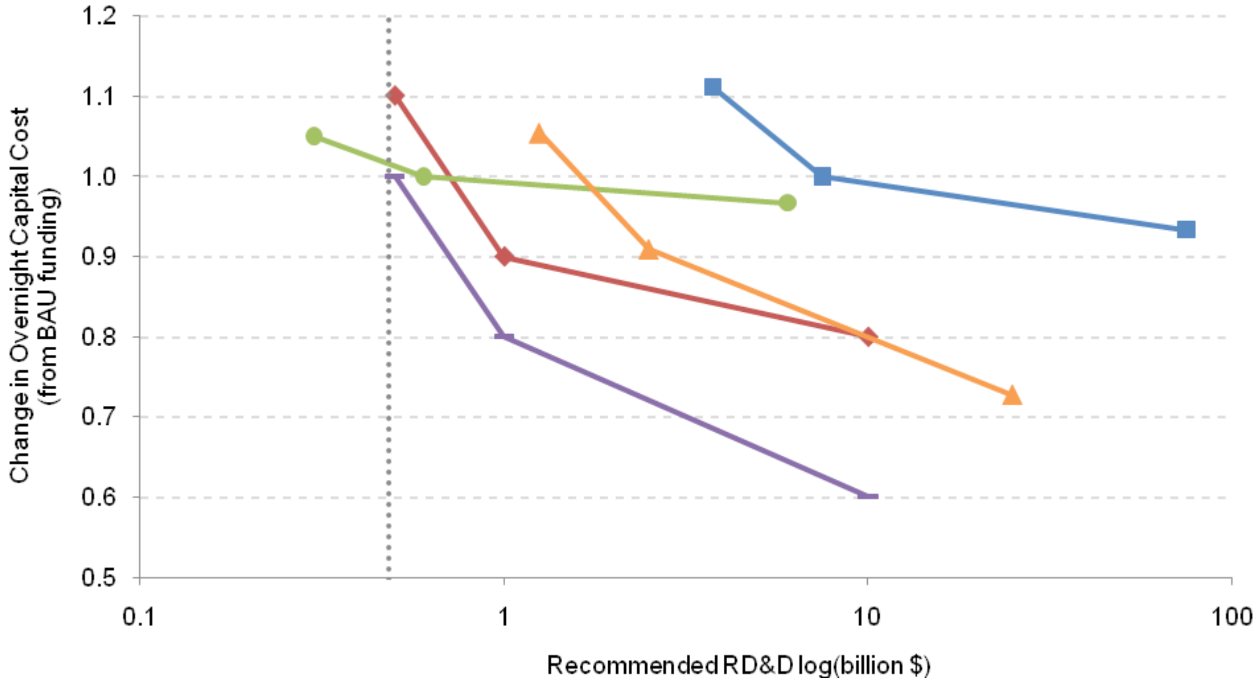


FIGURE A-33. Change in fossil plants with CCS overnight capital cost in 2030 compared to BAU funding scenario under each expert's recommended budget, half of recommended budget, and ten times recommended budget. The gray dotted line refers to DOE's FY 2009 budget for all fossil technologies ($480 million).

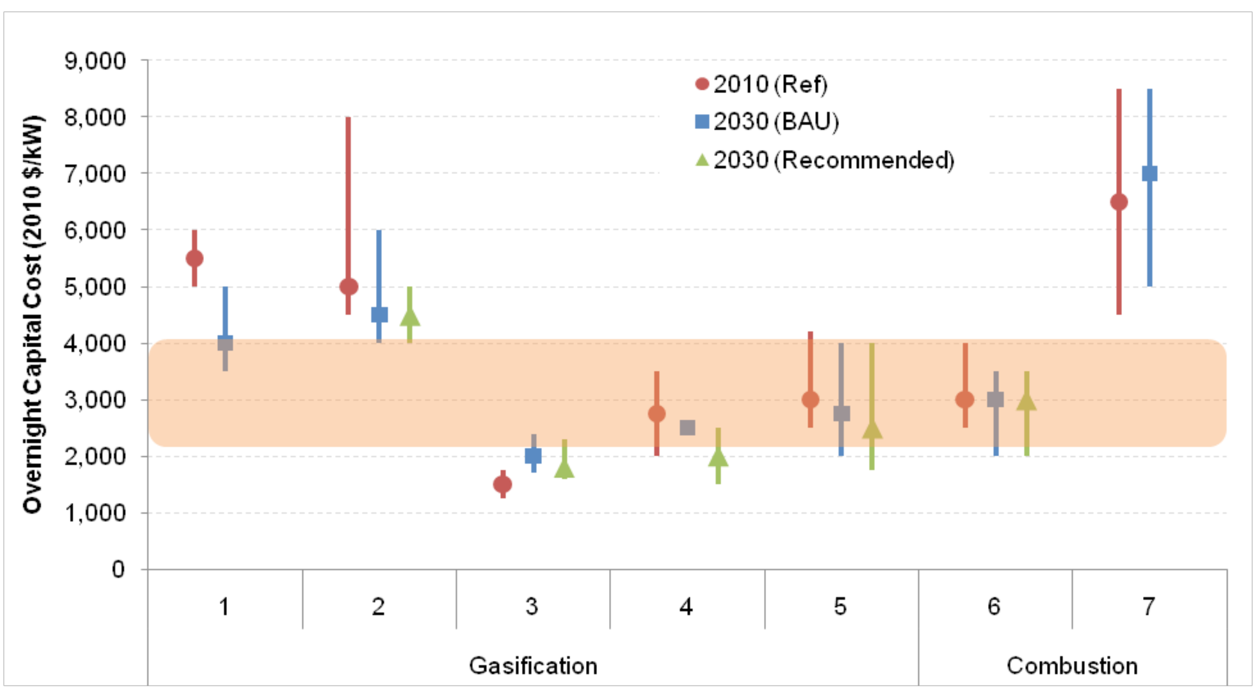


FIGURE A-34. Overnight capital cost in coal gasification and combustion plants with CCS in 2030.

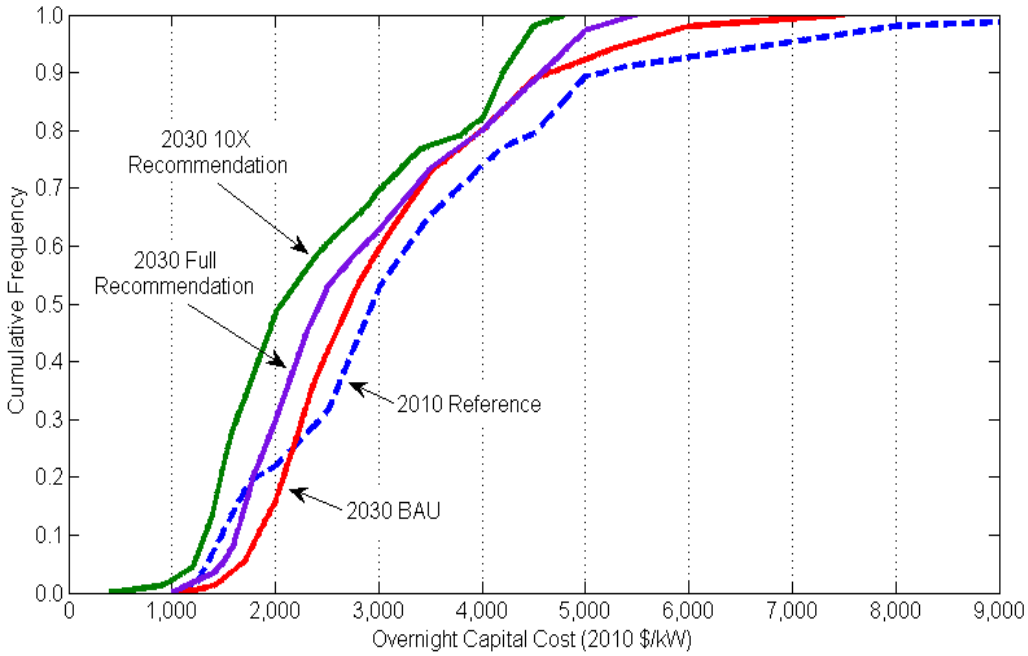


FIGURE A-35. Capital cos of a new coal power plant with CCS – simulated results from expert judgement.

A.5. Commercial building technology

We would like to thank the participating experts (Table A-9) for generously sharing their time and expertise. We randomly assigned each a number between 1 and 9 in our results.

We asked experts to estimate cost to build new commercial buildings and renovate existing commercial buildings to reduce energy consumption beyond compliance with the International Energy Conservation Code of 2009. Renovation costs were estimated for 2010, while new building costs were estimated for 2010 and 2030 if federal funding and policy for energy storage RD&D does not change over the 20-year period, as well as in 2030 for varying levels of their recommended budget and allocation. This budget and allocation is based on how they assigned an annual budget among the technologies in Table A-10.

Name	Affiliation
Sonya Bivins	General Services Administration
John Breshears	Architectural Applications
Fiona Cousins	Arup
Rick Diamond	Lawrence Berkeley Laboratory
Martine Dion	Symmes Maini & McKee Associates
Karin Giefer	Arup
Michael Holtz	Light Louver
Shanti Pless	National Renewable Laboratory
Juliet Walker	Arup

TABLE A-9. Experts who completed the elicitation about commercial building technology

Building components	Walls Roofing Insulation Windows Space heating Space cooling Water heating and cooling Lighting Plug and process loads On-site generation Ventilation Controls and monitoring
Benchmarking tools and activities	Computer simulation models and learning tools Building rating and education programs Building metering

Table A-10. Technologies presented to the experts

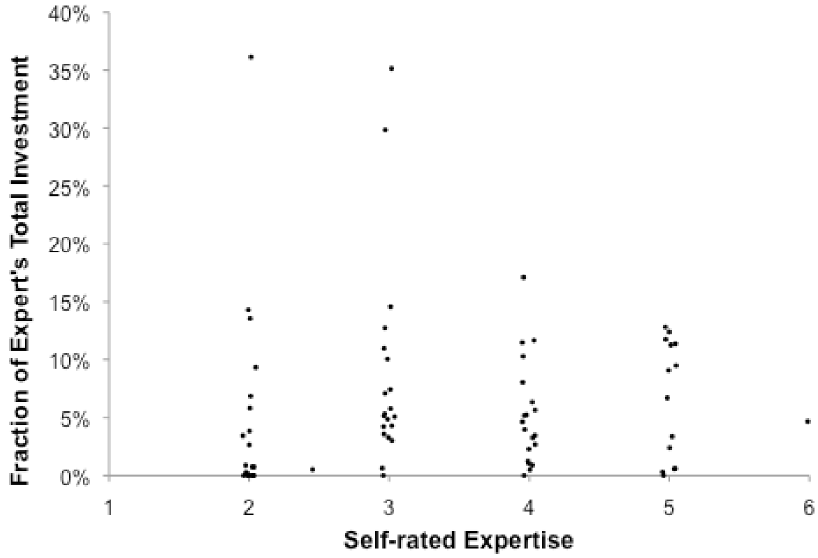


FIGURE A-36. Analysis of building expert bias in budget allocation toward their areas of expertise. Each point corresponds to the fraction of the recommended budget that an expert devoted to a particular technology (y-axis) and the expert's self-assessment of his level of expertise in the same technology (x-axis). The increasing density of the circles shows greater number of experts with same level of expertise and budget allocation to a given technology. No experts rated themselves as having no knowledge (level 1) of a technology.

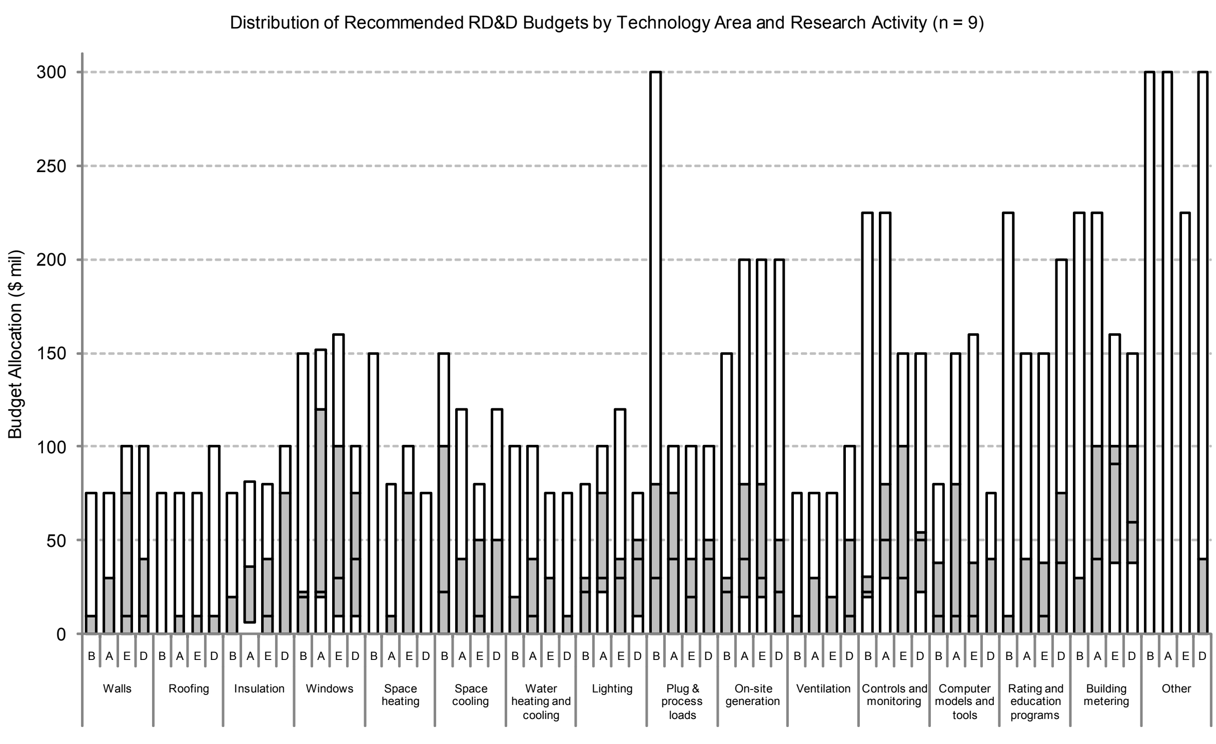


FIGURE A-37. Minimum, average, and maximum budget allocation over all experts per technology and innovation stage (million $). Basic = basic research, Applied = applied research, ExpPilots = experiments and field pilots, C Demo = commercial demonstration. Note that we collected a sample of experts that is representative of the field rather than a "statistically representative" sample. As such, each expert's opinion is an individual viewpoint in the field. However, we chose to show an "average" of the recommended percentage allocation because the maximum and minimum are extreme in many cases; the minimum budget allocation for a given technology is 0.

	Building Components												Benchmarking tools and activities			Others
	Walls	Roofing	Insulation	Windows	Space heating	Space cooling	Water heating and cooling	Lighting	Plug & process loads	On-site generation	Ventilation	Controls and monitoring	Computer models and tools	Rating and education programs	Building metering	Other
Basic Research	11.7	9.4	15.0	34.7	17.8	47.0	21.7	28.6	62.2	37.0	12.8	47.6	23.7	29.4	33.9	37.8
Applied Research	17.2	13.9	16.1	57.1	18.3	28.6	29.4	42.0	42.8	59.7	19.4	68.8	41.0	35.6	60.6	46.7
Experiments and Pilots	33.9	15.0	23.9	56.4	29.4	26.4	17.2	35.3	29.4	58.6	15.0	51.4	33.7	38.7	79.9	38.3
Commercial Demonstration	28.3	20.6	31.7	42.8	10.0	29.7	11.7	33.1	36.1	45.3	30.6	54.1	21.4	49.2	64.2	46.7
Total	91.1	58.9	86.7	191.1	75.6	131.8	80.0	139.0	170.6	200.7	77.8	221.9	119.7	152.9	238.5	169.4

FIGURE A-38. Average allocation of recommended annual federal building technology RD&D budget for 2010-2030 (million $)

	Building Components												Benchmarking tools and activities			Others
	Walls	Roofing	Insulation	Windows	Space heating	Space cooling	Water heating and cooling	Lighting	Plug & process loads	On-site generation	Ventilation	Controls and monitoring	Computer models and tools	Rating and education programs	Building metering	Other
Basic Research	0.4	0.2	0.4	1.3	0.3	1.8	0.9	1.6	2.1	1.8	0.6	2.2	1.1	0.8	0.9	0.7
Applied Research	0.7	0.3	0.6	4.4	0.4	1.2	1.3	2.3	2.1	3.0	0.9	4.7	2.8	1.1	2.3	0.8
Experiments and Pilots	1.4	0.4	0.8	2.6	1.0	1.3	0.7	1.7	1.3	2.9	0.4	2.2	1.5	1.6	4.9	0.7
Commercial Demonstration	1.2	0.8	1.3	2.8	0.3	1.3	0.4	2.1	2.0	2.4	1.4	3.6	1.2	2.9	3.7	0.9
Total	3.8	1.8	3.1	11.0	2.1	5.7	3.3	7.7	7.6	10.1	3.3	12.7	6.6	6.3	11.8	3.0

FIGURE A-39. Average allocation of recommended annual federal building technology RD&D budget for 2010-2030 (percentage of total)

We compared experts' budget recommendations against their self-assessed expertise per technology and conclude that there is insignificant bias in their budget allocations towards their areas of expertise. As shown in Figure A-36, experts were not biased to funding those areas in which they had high levels of expertise (4 - 6). Most experts recommended funding areas in which they had lower expertise levels.

The average annual spending recommendation among the experts is $678 million. The experts recommended a range of funding for building technology basic research, applied research, experiments and field demonstration, and commercial demonstration. Experts designated the "Other" category to user behavior and integrated design. We show the group's recommended funding allocation as dollar and percentage allocation of the experts' budgets. Figure A-37 shows the range of absolute budget allocation among the 9 experts who participated in the survey. We plot minimum, mean, and maximum allocation amount per innovation stage and technology or research area, as well as the 25th and 75th percentiles. Figure A-38 shows the values for the mean budget allocation, by innovation stage and technology, shown in Figure A-37. Figure A-39 shows the same information as percentage of total budget. As shown in Figures A-37 to A-38, the greatest amounts of spending on a dollar basis are allocated to applied research for windows and controls and monitoring, as well as building metering experiments and pilots. Experts further defined their recommendations for controls and monitoring and building metering to include full system monitoring as well as metering down to a component level.

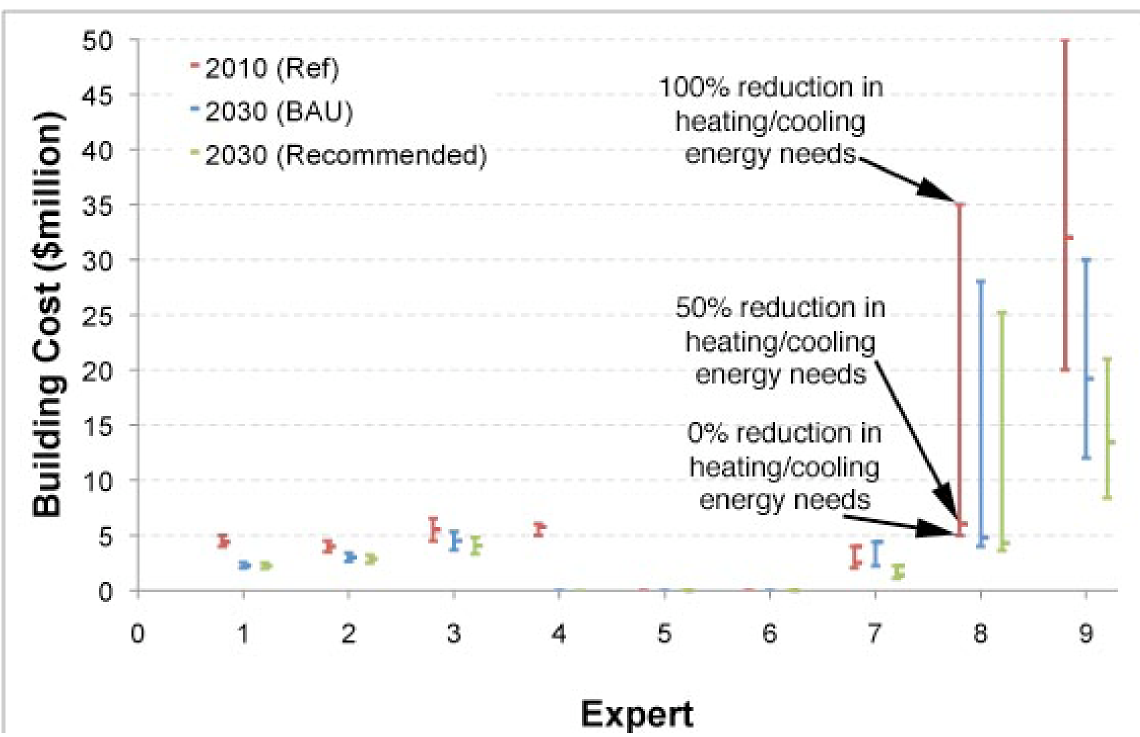
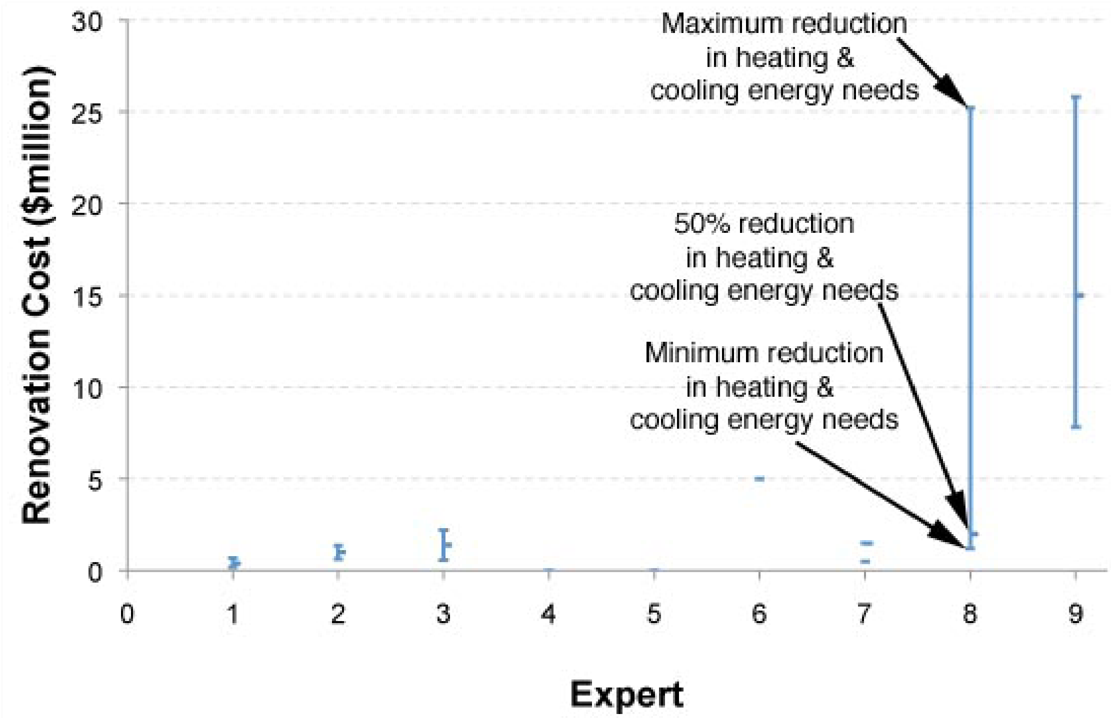


FIGURE A-40. Range of cost build new 20,000 ft2 commercial buildings in 2010, and 2030 by experts under business-as-usual federal building technology RD&D funding and experts' recommended RD&D funding, to reduce heating and cooling energy consumption beyond compliance with IECC 2009. Expert 4 did not provide 2030 cost estimates. Experts 5 and 6 did not provide cost estimates.



Experts' ranges of heating and cooling energy reduction achievable by renovation (%)								
Expert	**1**	**2**	**3**	**6**	**7 (low)**	**7 (high)**	**8**	**9**
Minimum	30	50	10	10	0	10	50	10
Maximum	100	100	100	50	100	100	100	100
Minimum = Level at which costs will be incurred for renovation								
Maximum = Maximum level of reduction that can be achieved by renovation								

FIGURE A-41. Range of cost renovate existing 20,000 ft2 commercial buildings in 2010 to reduce heating and cooling energy consumption beyond compliance with IECC 2009. Experts 4 and 5 did not provide cost estimates.

Experts provided judgment on cost to reduce heating and cooling energy consumption beyond the IECC 2009 by new construction or renovating existing buildings. We asked experts to provide 2010 renovation cost estimates, and obtained new construction cost estimates for 2010 and 2030. Figures A-42 and A-43 show the cost to achieve up to 100% reduction in heating and cooling energy consumption compared to compliance with the IECC 2009. The bottom of the range is 0% reduction compared to IECC 2009, and the top of the range is 100% reduction compared to IECC 2009. The point shown between the top and bottom of the range is the cost to achieve 50% reduction in heating and cooling energy consumption compared to compliance with the IECC 2009. As Figures A-40 and A-41 show, the experts appear divided. For example (Figure A-40), Experts 1, 2, 3, 4, and 7 believe that up to 100% reduction in 2010 heating and cooling energy consumption can be achieved for less than $800,000 but experts 8 and 9 believe that the same reductions will cost more than $35 million. The experts are similarly divided when it comes to building costs in 2030. Experts 1, 2, 3, 4, and 7 believe future building costs will be less than $500,000 but experts 8 and 9 believe future building costs to achieve 100% heating

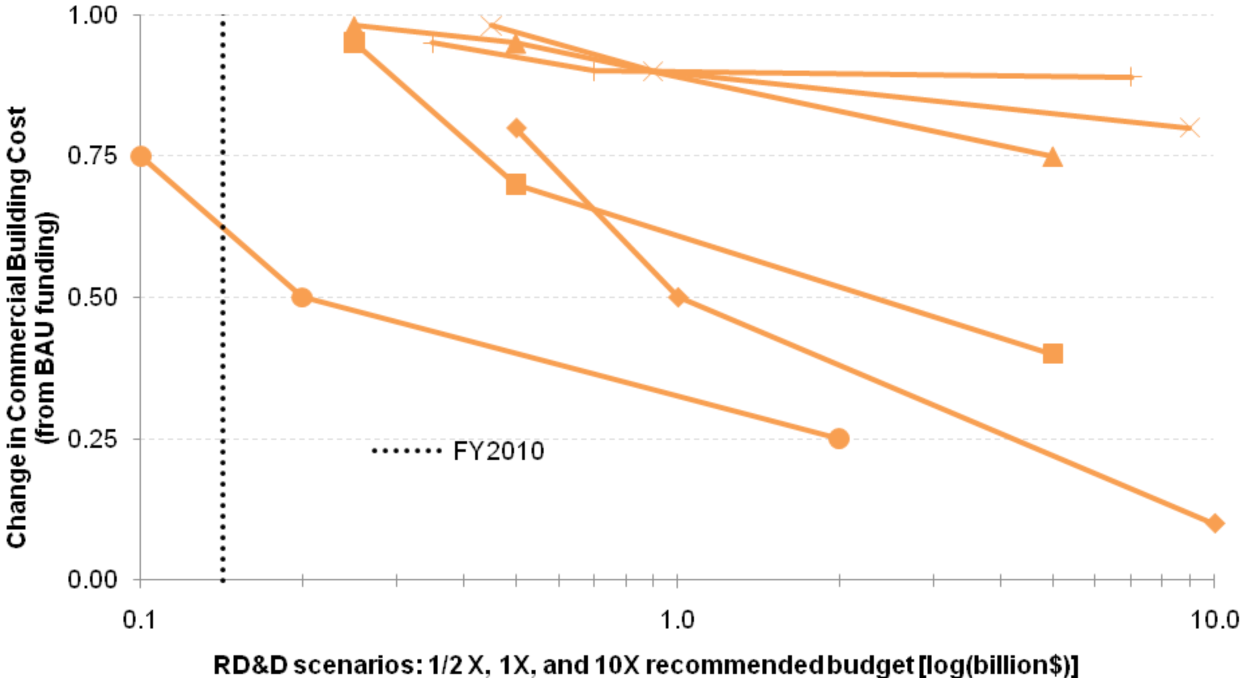


FIGURE A-42. Change in new commercial building cost (20,000 ft2) in 2030 compared to BAU funding scenario under each expert's recommended budget, half of recommended budget, and ten times recommended budget. The gray dotted line refers to FY 2010 budget for all building technologies RD&D, $144 million.

and cooling energy consumption will be as much as $30 million under the BAU funding scenario and $25 million with a revamped budget.

Figure A-41 shows 7 of the 9 experts' cost estimates of reducing heating and cooling energy consumption for an existing 20,000 ft2 commercial building. Experts were asked to estimate renovation costs up to 100% heating and cooling energy reduction. As shown in the table below the chart, some experts did not believe that 100% reduction could be achieved, or believed reductions up to a set point (e.g., 30% for expert 1) could be achieved at no cost. Again, experts appear divided. Experts 1, 2, 3, 6, and 7 believe that up to 100% reduction in heating and cooling energy consumption could be achieved for less than $5 million, but experts 8 and 9 believed that the same reductions would cost $25 million or more.

Figure A-42 compares experts' business as usual and anticipated building costs per their recommended budgets to identify the impact of increasing RD&D investments over the BAU scenario. Experts appear to believe that with increased funding, building costs will decrease over the business as usual. Recall that experts recommended funding amounts and allocation. The experts, however, are in disagreement about how much benefit can be gained for spending additional money. Current building technology innovation spending is $144 million. If spending were increased to the experts' recommended $678 million, building costs could be reduced 5-52 percent. Still, all experts do appear to agree that changing spending and budget allocation will reduce the costs of buildings with lower heating and cooling energy needs than IECC 2009 compliant buildings.

A.6. Light duty vehicles

We would like to thank the participating experts (Table A-11) for generously sharing their time and expertise. We randomly assigned each a number between 1 and 9 in our results.

We asked experts to estimate cost and fuel consumption of different drive train light duty vehicles in

Name	Affiliation
Mark Alexander	Electric Power Research Institute
John German	The International Council for Clean Transportation
Deborah Gordon	
John Johnson	
Terry Penney	National Renewable Energy Laboratory
William Powers	
Danilo Santini	Argonne National Laboratory
Luke Tonachel	National Resources Defense Council
Ed Wall	U.S. Department of Energy

TABLE A-11. Experts who completed the elicitation about light duty vehicles technology

Drive trains	Spark-ignition internal combustion engine Compression-ignition internal combustion engine Conventional hybrid Plug-in hybrid Battery electric Hydrogen internal combustion engine
Battery and other energy storage technologies	Li-ion batteries Lead acid batteries Ni-MH, Ni-Cd, Ni-Zn batteries Ultracapacitors Flow batteries (e.g. Zn-Br) Metal-air batteries (e.g. Zn-air) High temperature batteries (e.g. Na-S, Na-Ni-Cl, Li-S) Battery manufacturing
Hydrogen and fuel cells	Solid-oxide, alkaline, polymer electrolyte membrane Materials for fuel cells H2 storage/tank technology
Other vehicle or ancillary technologies	Vehicle materials Modeling/simulation Electric vehicle or other fuel charging infrastructure Advanced engines for novel fuels Compressed natural gas

TABLE A-12. Technologies presented to the experts

2010 and in 2030 if federal funding and policy for vehicles RD&D does not change over the 20-year period, as well as in 2030 for varying levels of their recommended budget and allocation. This budget and allocation is based on how they assigned an annual budget among the technologies in Table A-12.

We compared experts' budget recommendations against their self-assessed expertise per technology and conclude that in a handful of instances there is a bias in their budget allocations towards their areas of expertise. As shown in Figure A-43, some allocations were toward areas in which the experts had high levels of expertise (4 to 6), though many also allocated low percentages of funding toward their areas of expertise.

The average annual spending recommendation among the experts is $2.05 billion. The experts recommended greater amounts of federal funding for basic and applied research, with particular emphasis on novel concepts of energy storage, materials, the "other" category, and Li-ion batteries. The experts designated the "other" category as electric vehicle supply equipment; infrastructure for delivery, storage, and dispensing of alternative fuels; advanced engines for conventional fuels and fuels projected to have the potential to develop a commercial infrastructure; thermoelectric devices and thermal recovery; advanced fuels technology, recycling; and materials manufacturing. We show the group's recommended funding

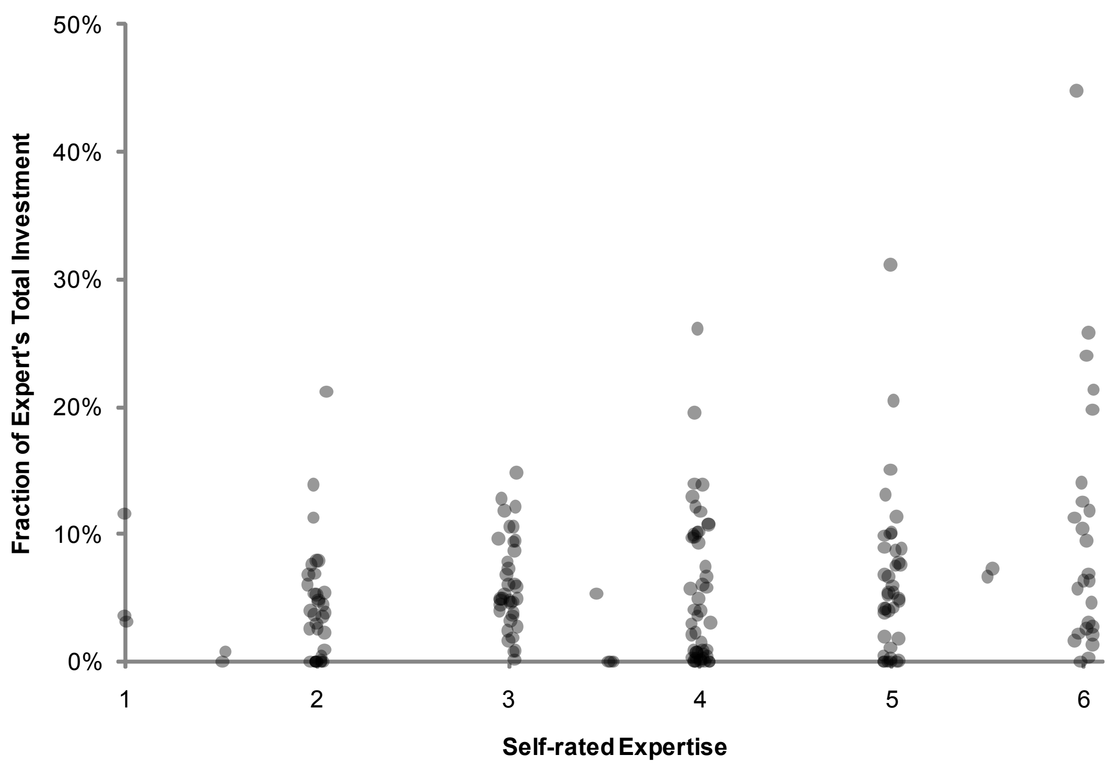


FIGURE A-43. Analysis of light duty vehicle technology expert bias in budget allocation toward their areas of expertise. Each point corresponds to the fraction of the recommended budget that an expert devoted to a particular technology (y-axis) and the expert's self-assessment of his level of expertise in the same technology (x-axis). The increasing density of the circles shows greater number of experts with same level of expertise and budget allocation to a given technology.

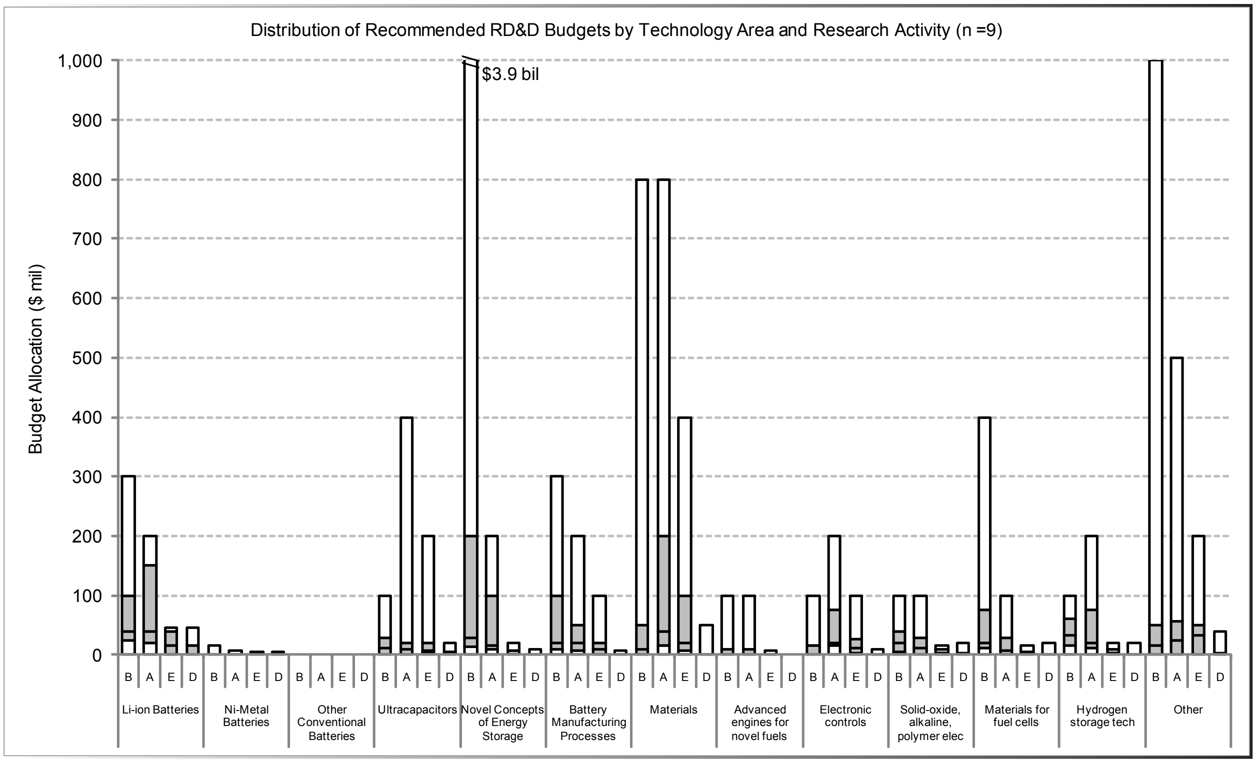


FIGURE A-44. Minimum, average, and maximum budget allocation over all experts per technology and innovation stage (million $). Basic = basic research, Applied = applied research, ExpPilots = experiments and field pilots, C Demo = commercial demonstration. Note that we collected a sample of experts that is representative of the field rather than a "statistically representative" sample. As such, each expert's opinion is an individual viewpoint in the field. However, we chose to show an "average" of the recommended percentage allocation because the maximum and minimum are extreme in many cases.

allocation as dollar and percentage allocation of the experts' budgets. Figure A-44 shows the range of absolute budget allocation among the nine experts who participated in the survey. We plot minimum, mean, and maximum allocation amount per innovation stage and technology, as well as 25th and 75th percentiles. Figure A-45 shows the values for the mean budget allocation, by innovation stage and technology, shown in Figure A-44. Figure A-46 shows the same information as percentage of total budget.

Figures A-46 and A-47 show the purchase cost experts projected for various light duty vehicle drive trains by experts who provided these projections. Almost all experts projected a decline in costs in 2030 under their respective recommended funding levels compared to BAU funding to 2030. (The exception is expert one who projected a static cost for advanced internal combustion and conventional hybrid drive trains an any funding level.) Expert one was relatively more uncertain about costs compared to the other experts, especially for hydrogen fuel cell drive train vehicles. The "other" category was specified by the experts as an extended range electric vehicle like the Chevrolet Volt and a flexible fuel plug-in hybrid electric vehicle capable of running on ethanol, gasoline, or methanol. The experts were generally

	Battery and Other Energy Storage Technologies						Cross-Cutting Technologies			Hydrogen and Fuel Cells			Others
	Li-ion Batteries	Ni-Metal Batteries	Other Conventional Batteries	Ultracapacitors	Novel Concepts of Energy Storage	Battery Manufacturing Processes	Materials	Advanced engines for novel fuels	Electronic controls	Solid-oxide, alkaline, polymer elec	Materials for fuel cells	Hydrogen storage tech	Other
Basic Research	5.1	0.6	0.0	1.8	8.9	3.9	2.6	0.9	1.2	2.3	3.4	3.1	3.8
Applied Research	5.3	0.3	0.0	3.6	3.2	3.2	5.7	0.9	3.6	2.1	1.6	3.4	3.7
Experiments and Pilots	2.7	0.2	0.0	2.4	0.8	1.8	3.3	0.3	2.3	0.7	0.4	0.9	3.6
Commercial Demonstration	1.9	0.1	0.0	0.6	0.2	0.3	0.8	0.0	0.3	0.4	0.3	0.3	1.1
Total	15.0	1.2	0.0	8.3	13.1	9.2	12.3	2.1	7.5	5.5	5.8	7.8	12.1

FIGURE A-45. Average allocation of recommended annual federal light duty vehicle RD&D budget for 2010-2030 (million $)

	Battery and Other Energy Storage Technologies						Cross-Cutting Technologies			Hydrogen and Fuel Cells			Others
	Li-ion Batteries	Ni-Metal Batteries	Other Conventional Batteries	Ultracapacitors	Novel Concepts of Energy Storage	Battery Manufacturing Processes	Materials	Advanced engines for novel fuels	Electronic controls	Solid-oxide, alkaline, polymer elec	Materials for fuel cells	Hydrogen storage tech	Other
Basic Research	79.5	2.3	0.0	23.6	491.2	78.6	108.0	14.9	22.3	31.7	85.7	38.9	130.4
Applied Research	78.7	1.5	0.0	53.8	53.1	45.7	162.2	14.9	50.6	26.1	25.6	51.6	77.1
Experiments and Pilots	19.0	1.0	0.0	32.3	4.5	27.7	90.3	1.3	23.0	5.2	3.8	6.5	44.8
Commercial Demonstration	12.4	0.6	0.0	3.7	1.7	1.5	6.4	0.0	1.6	3.2	2.6	2.6	6.5
Total	189.6	5.4	0.0	113.3	550.5	153.4	366.9	31.1	97.5	66.2	117.7	99.7	258.7

FIGURE A-46. Average allocation of recommended annual federal light duty vehicle RD&D budget for 2010-2030 (percentage of total) more optimistic about cost reductions than the MIT On the Road report, except for expert three and except for hydrogen fuel cell vehicles. Cost reductions compared to BAU costs increase with increasing funding, with decreasing marginal returns. One expert recommended a very high budget and therefore did not think ten times that amount was reasonable and did not provide cost projections at that funding level. One experts cost reduction projections for hydrogen were relatively lower than cost projections for other technology and by other experts.

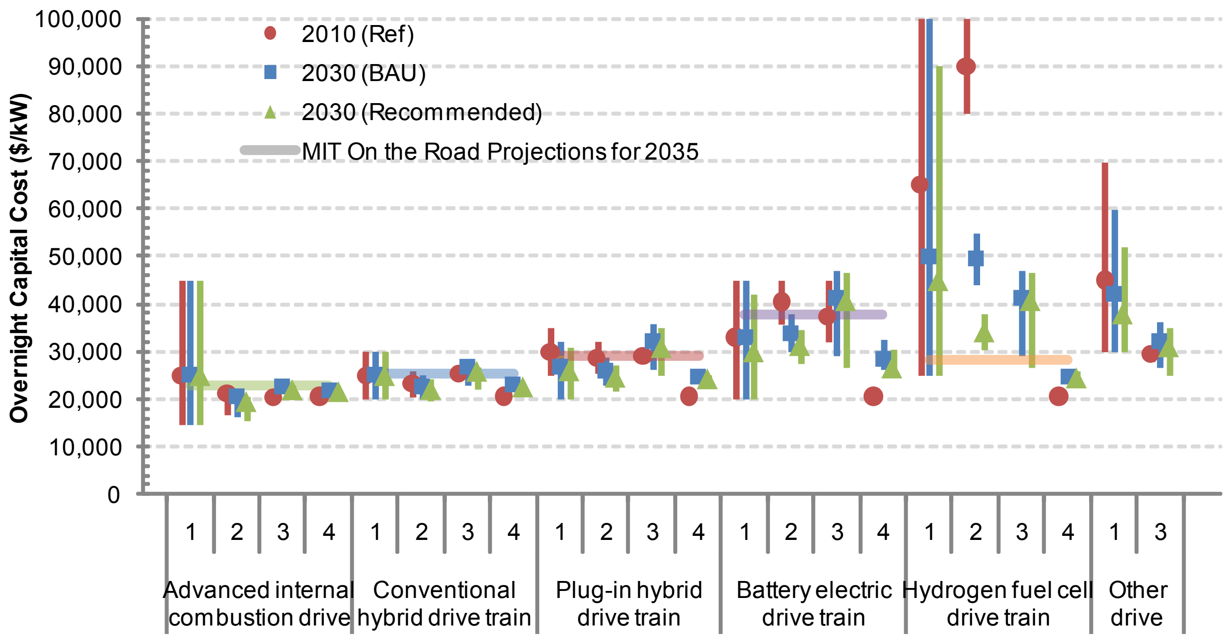


FIGURE A-47. Median, 10th percentile, and 90th percentile light duty vehicle overnight capital cost estimates in 2010, and 2030 by experts under business-as-usual federal RD&D funding and experts' recommended RD&D funding compared with the DOE best estimate of overnight capital cost in 2030.

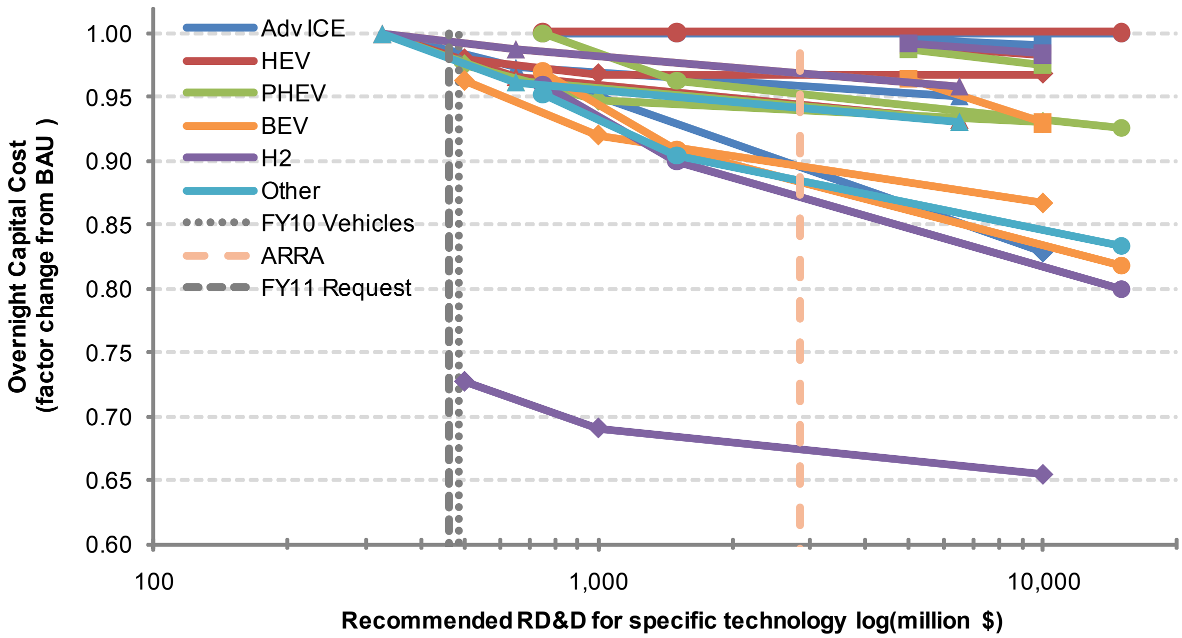


FIGURE A-48. Change in light duty vehicle technology cost in 2030 compared to BAU funding scenario under each expert's recommended budget, half of recommended budget, and ten times recommended budget. The gray dotted line refers to DOE's FY 2009 budget for light duty vehicle technologies.

A.7. Solar photovoltaic (PV) technology

We would like to thank the participating experts (Table A-13) for generously sharing their time and expertise. We randomly assigned each a number between 1 and 10 in our results.

Name	Affiliation
Allen Barnett	University of Delaware
Sarah Kurtz	NREL
Bill Marion	NREL
Robert McConnell	Amonix, Inc.
Danielle Merfeld	GE Global research
John Paul Morgan	Morgan Solar
Sam Newman	Rocky Mountain Institute
Paul R. Sharps	Emcore Photovoltaics
Sam Weaver	Cool Energy
John Wohlgemuth	NREL

TABLE A-13. Experts who completed the elicitation about solar PV technology

We asked experts to estimate cost and performance of solar photovoltaic modules in the commercial, residential, and utility sectors in 2010 and in 2030 if federal funding and policy for solar RD&D does not change over the 20-year period, as well as in 2030 for varying levels of their recommended budget and allocation. This budget and allocation is based on how they assigned an annual budget among the technologies in Table A-14.

We compared experts' budget recommendations against their self-assessed expertise per technology and conclude that there is a slight bias in their budget allocations towards their areas of expertise. As shown in Figure A-49, some allocations were toward areas in which the experts had high levels of expertise (4 to 6), though many also allocated low percentages of funding toward their areas of expertise. Most experts recommended funding areas in which they had lower expertise levels.

The average annual spending recommendation among the experts is $409 million. The experts recommended a range of funding for solar photovoltaic technology basic research, applied research, experiments and field demonstration, and commercial demonstration. Experts designated the "Other" technology category in the allocation as storage, resource assessment, grid integration and support, reliability, stimulated emission concentrating photovoltaics, and up- and down- conversion. We show the group's recommended funding allocation as dollar and percentage allocation of the experts' budgets. Figure A-50 shows the range of absolute budget allocation among the twelve experts who participated in the survey. We plot minimum, mean, and maximum allocation amount per innovation stage and technology, as well as 25th and 75th percentiles. Figure A-51 shows the values for the mean budget allocation, by innovation stage and technology, shown in Figure A-50. Figure A-52 shows the same information as percentage of total budget.

Figures A-53 through A-55 show the overnight capital cost experts projected for modules in the commercial, residential, and utility sectors, respectively. All experts projected a decline in costs in 2030 under BAU funding, and a further decline (for those who reported) under their respective recommended funding levels. A couple experts (9 and 11) were particularly uncertain about 2010 costs. Under BAU funding, 2030, experts' 50th percentile commercial module cost projections range from \$0.50/W to \$2.25/W between experts. Under experts' recommended funding levels, they drop to between \$0.40/W to \$2.00/W between experts (Figure A-53). For residential, the range is \$0.75/W to \$2.40/W under BAU

Crystalline Si	c-Si mc-Si, wafer based mc-Si, ribbon or sheet mc-Si, novel
Thin film	Si/multijunction a-Si Thin Si CdTe CIS and related alloys Polycrystalline Novel materials
Concentrator	c-Si, up to 100x c-Si, 100-1000x III-V multijunction, up to 100x III-V multijunction, 100-1000x Novel
Excitonic	Organic, small molecule Organic, polymer Dye-sensitized TiO_2 Hybrid organic/inorganic Quantum dot composite
Novel high-efficiency	Hot carrier Multiple electron-hole pair Multiband Frequency up/down conersion Plasmonics Thermophotovoltaics
Inverters	Inverter

TABLE A-14. Technologies presented to the experts

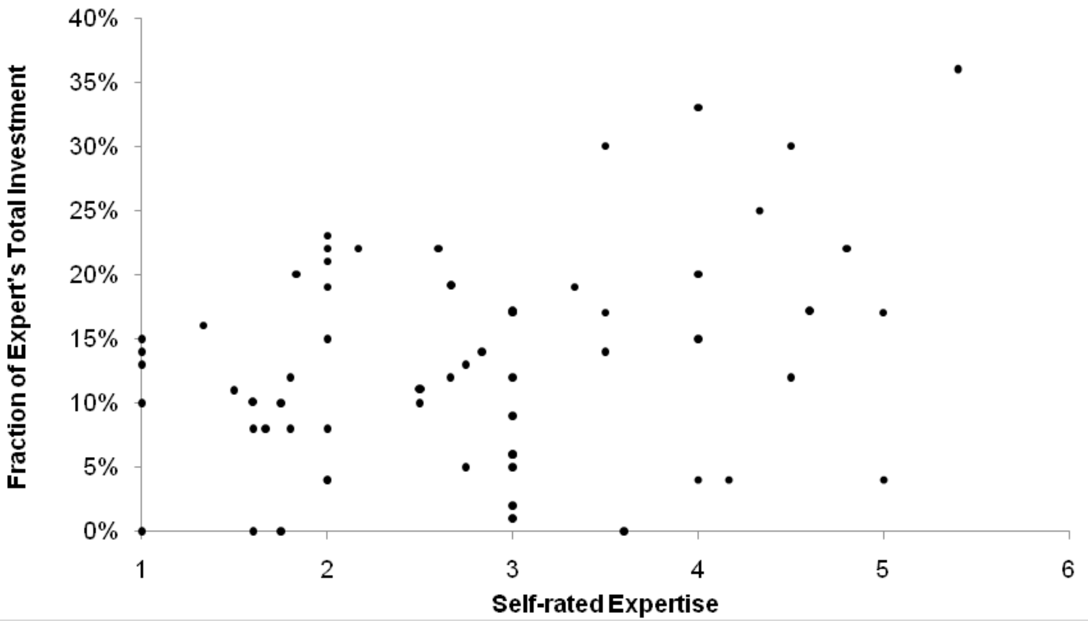


FIGURE A-49. Analysis of solar PV expert bias in budget allocation toward their areas of expertise. Each point corresponds to the fraction of the recommended budget that an expert devoted to a particular technology (y-axis) and the expert's self-assessment of his level of expertise in the same technology (x-axis). The increasing density of the circles shows greater number of experts with same level of expertise and budget allocation to a given technology.

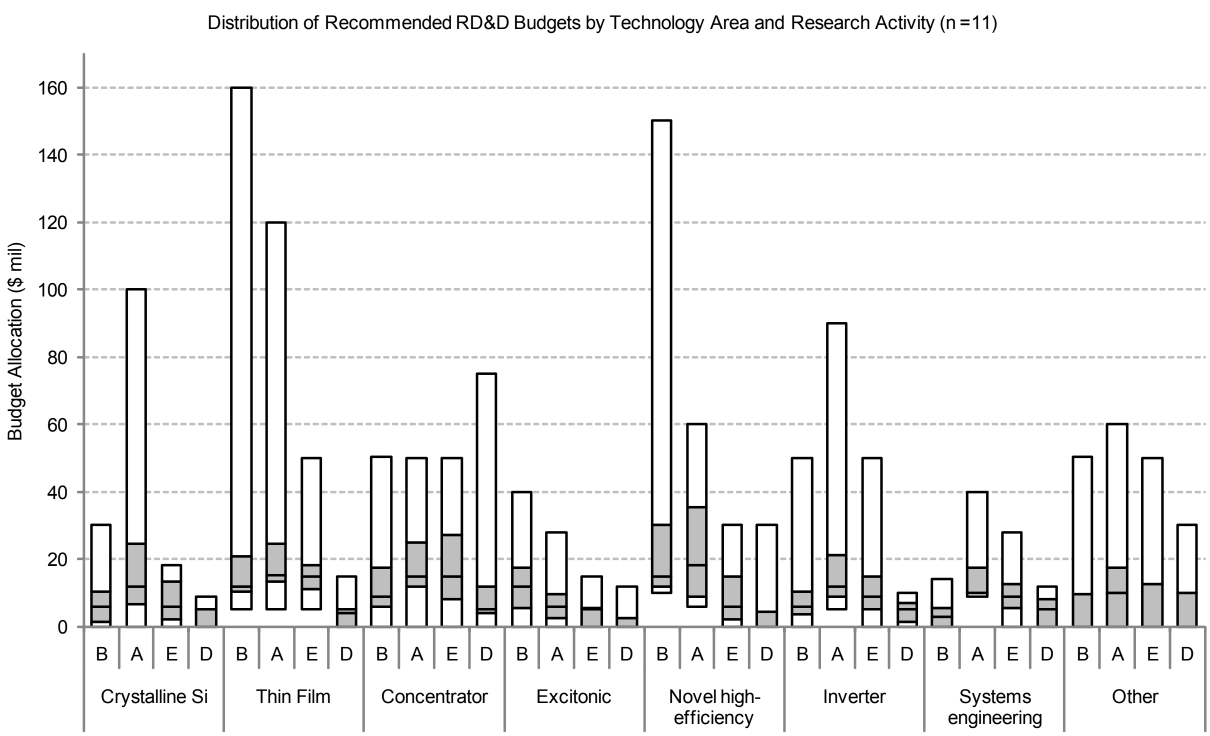


FIGURE A-50. Minimum, average, and maximum budget allocation over all experts per technology and innovation stage (million $). Basic = basic research, Applied = applied research, ExpPilots = experiments and field pilots, C Demo = commercial demonstration. Note that we collected a sample of experts that is representative of the field rather than a "statistically representative" sample. As such, each expert's opinion is an individual viewpoint in the field. However, we chose to show an "average" of the recommended percentage allocation because the maximum and minimum are extreme in many cases.

	Crystalline Si	Thin Film	Concentrator	Excitonic	Novel high-efficiency	Inverter	Systems engineering	Other
Basic Research	8.1	27.2	13.7	14.1	33.0	13.0	4.2	8.0
Applied Research	22.8	27.3	19.4	7.6	24.9	21.7	16.1	13.9
Experiments and Pilots	7.9	16.9	18.6	4.6	9.6	13.8	10.9	10.1
Commercial Demonstration	2.2	4.5	13.1	2.1	4.4	4.6	4.6	6.4
Total	42.6	80.2	64.6	26.6	71.1	51.8	37.1	37.2

FIGURE A-51. Average allocation of recommended annual solar PV technology RD&D budget for 2010-2030 (million $)

	Crystalline Si	Thin Film	Concentrator	Excitonic	Novel high-efficiency	Inverter	Systems engineering	Other
Basic Research	2.4	5.1	3.6	3.2	6.6	2.8	1.4	2.2
Applied Research	5.5	6.1	5.4	2.2	5.6	4.8	4.4	3.0
Experiments and Pilots	2.5	4.3	5.1	1.3	2.5	3.4	3.5	2.2
Commercial Demonstration	0.5	1.4	3.5	0.6	1.1	1.3	1.5	1.5
Total	10.8	17.2	17.9	6.9	15.1	11.9	11.3	8.9

FIGURE A-52. Average allocation of recommended annual federal building technology RD&D budget for 2010-2030 (percentage of total).

funding, falling to \$0.30/W to \$1.60/W under experts' recommended funding levels (Figure A-54). In the utility sector, the range is \$0.35/W to \$1.25/W under BAU funding, falling to \$0.30/W to \$0.85/W under experts' recommended funding levels (Figure A-55).

Figures A-56 through A-58 show the efficiency experts projected for modules in the commercial, residential, and utility sectors, respectively. All experts projected an increase in efficiency in 2030 under BAU funding, and a further increase (for those who reported) under their respective recommended funding levels. Experts 2, 4, and 10 were more uncertain about efficiency levels for commercial and residential modules, while expert 1 and 10 were more uncertain about utility module efficiency. Under BAU funding, in 2030, experts' 50th percentile commercial module efficiency projections range from 15% to 32% between experts. Under experts' recommended funding levels, they increase to between 18% and 40%, among experts (Figure A-56). For residential, the range is 17% to 32% under BAU funding, increasing to 18% to 40% under experts' recommended funding levels (Figure A-57). In the utility sector, the range is 15% to 34% under BAU funding, rising to 15% to 40% under experts' recommended funding levels (Figure A-58).

Experts' cost and efficiency projections at not only their recommended funding levels but also half and ten times those levels provide insight into the range of cost reduction to be gained for spending the experts' average recommended budget of \$410 million (Figures A-59 and A-60).

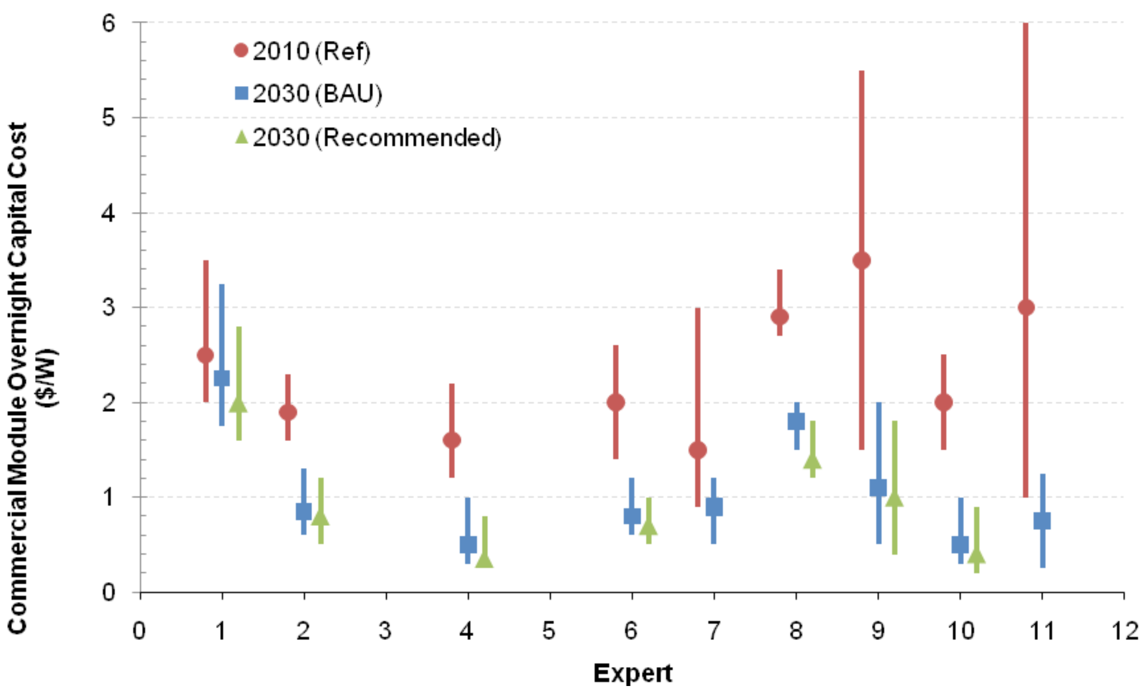


FIGURE A-53. Median, 10th percentile, and 90th percentile solar PV commercial module overnight capital cost estimates by experts in 2010, and 2030 under business-as-usual federal solar PV RD&D funding and experts' recommended RD&D funding.

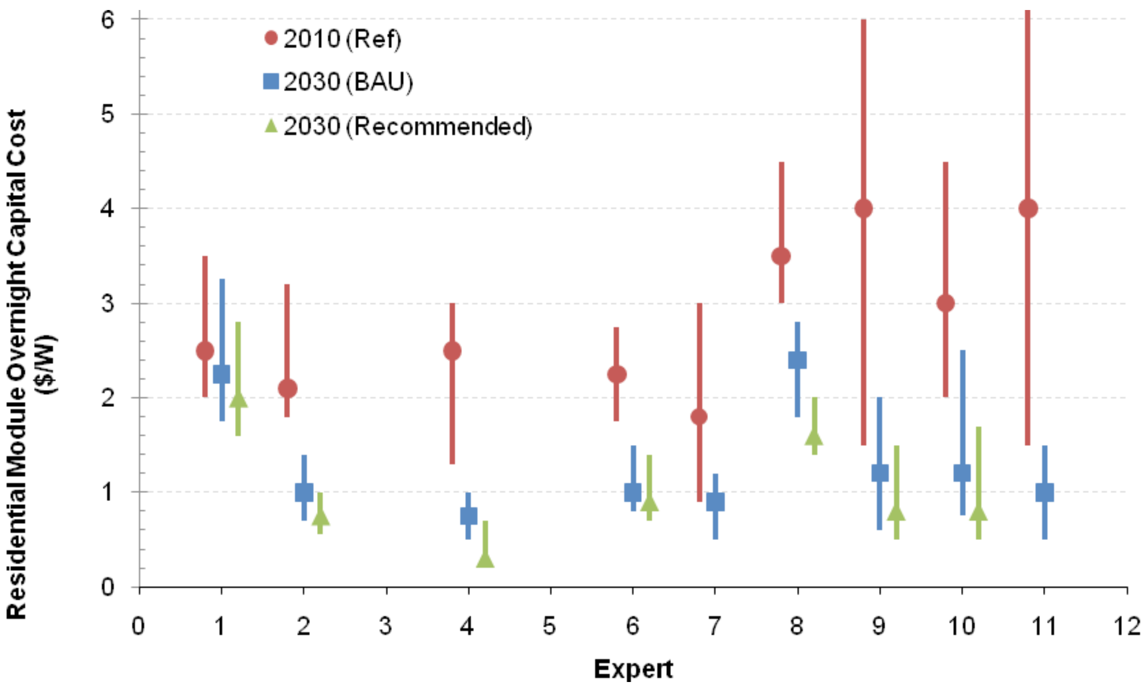


FIGURE A-54. Median, 10th percentile, and 90th percentile solar PV residential module overnight capital cost estimates by experts in 2010, and 2030 under business-as-usual federal solar PV RD&D funding and experts' recommended RD&D funding.

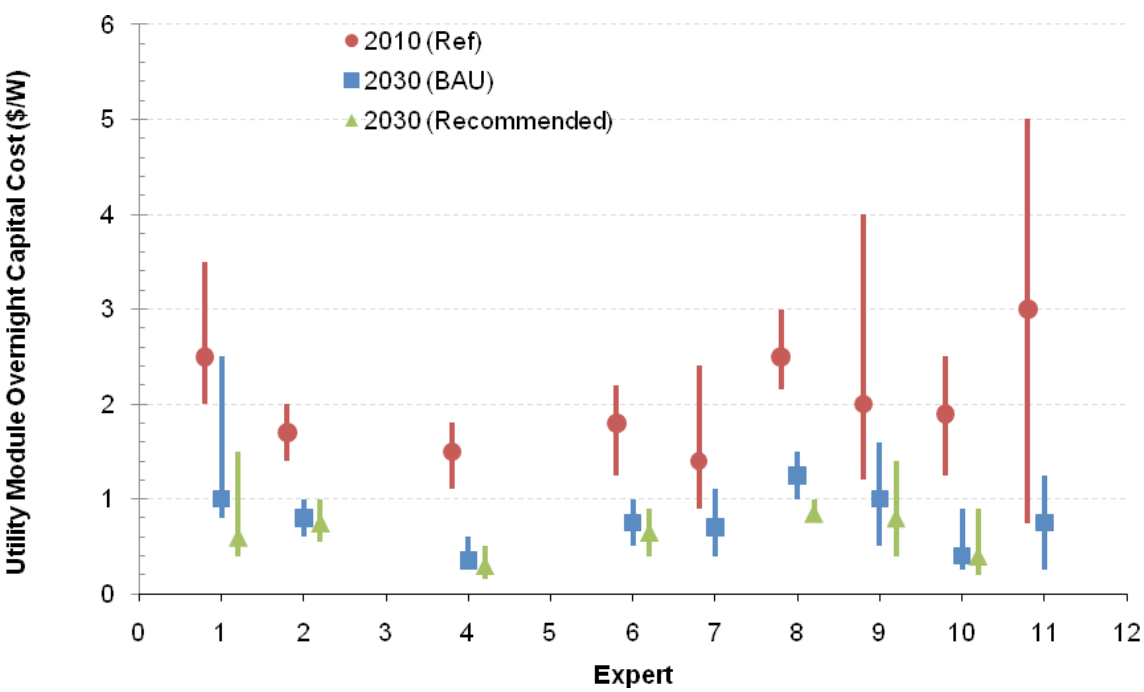


FIGURE A-55. Median, 10th percentile, and 90th percentile solar PV utility module overnight capital cost estimates by experts in 2010, and 2030 under business-as-usual federal solar PV RD&D funding and experts' recommended RD&D funding.

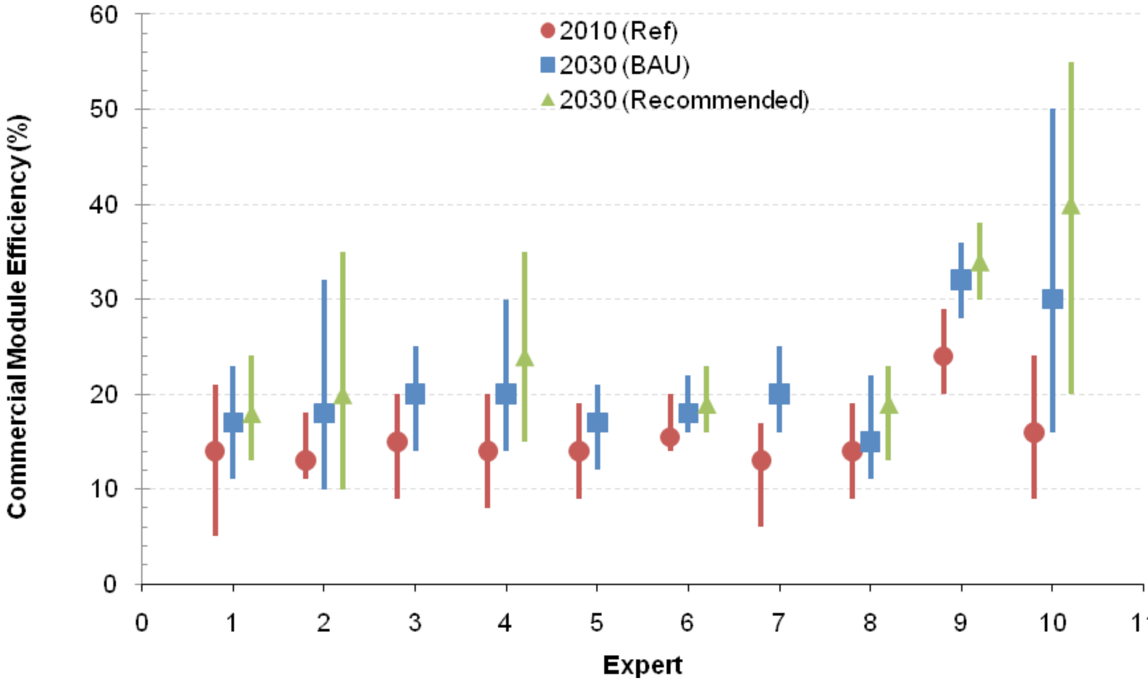


FIGURE A-56. Median, 10th percentile, and 90th percentile solar PV commercial module efficiency estimates by experts in 2010, and 2030 under business-as-usual federal solar PV RD&D funding and experts' recommended RD&D funding.

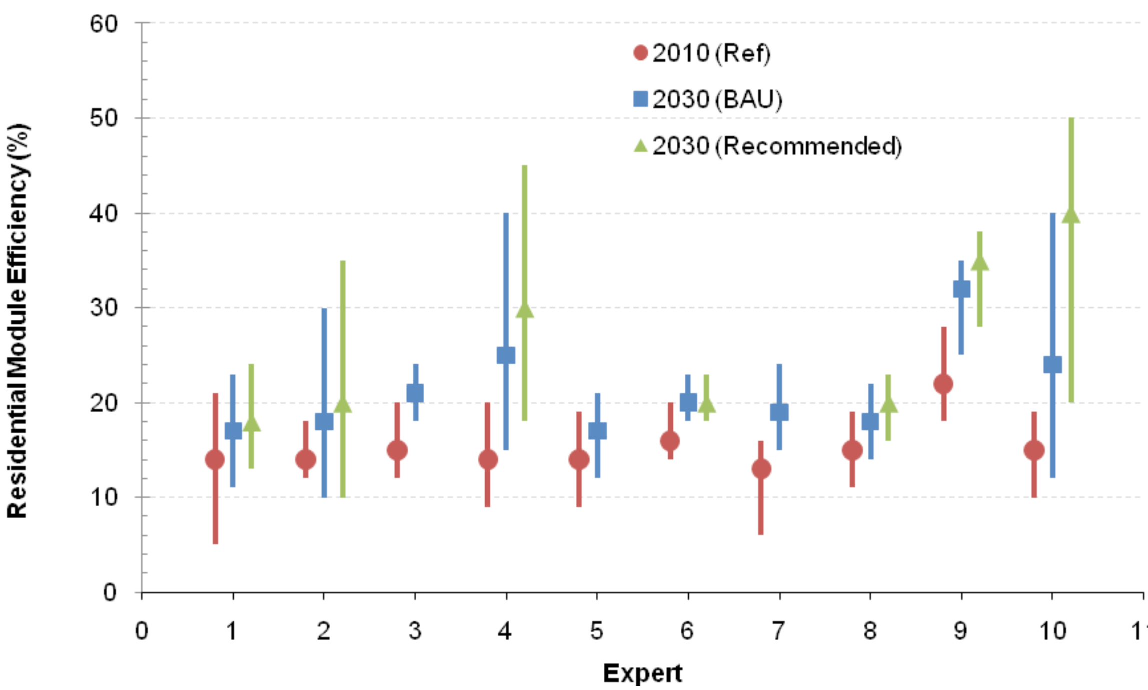


FIGURE A-57. Median, 10th percentile, and 90th percentile solar PV residential module efficiency estimates by experts in 2010, and 2030 under business-as-usual federal solar PV RD&D funding and experts' recommended RD&D funding.

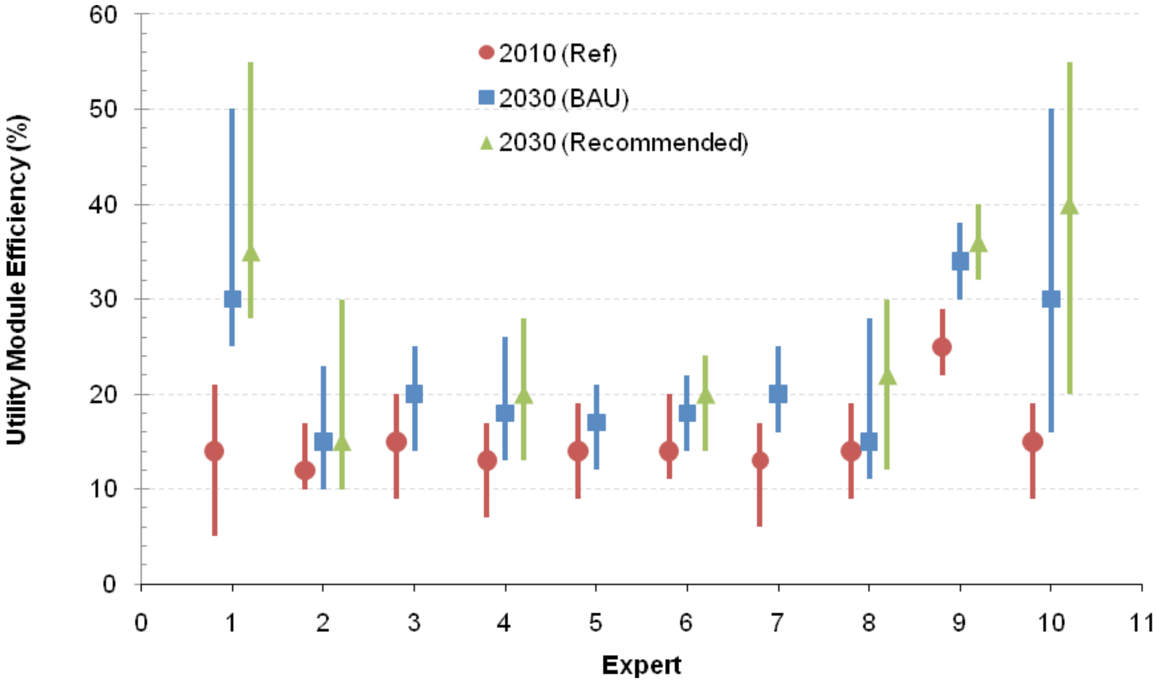


FIGURE A-58. Median, 10th percentile, and 90th percentile solar PV utility module efficiency estimates by experts in 2010, and 2030 under business-as-usual federal solar PV RD&D funding and experts' recommended RD&D funding.

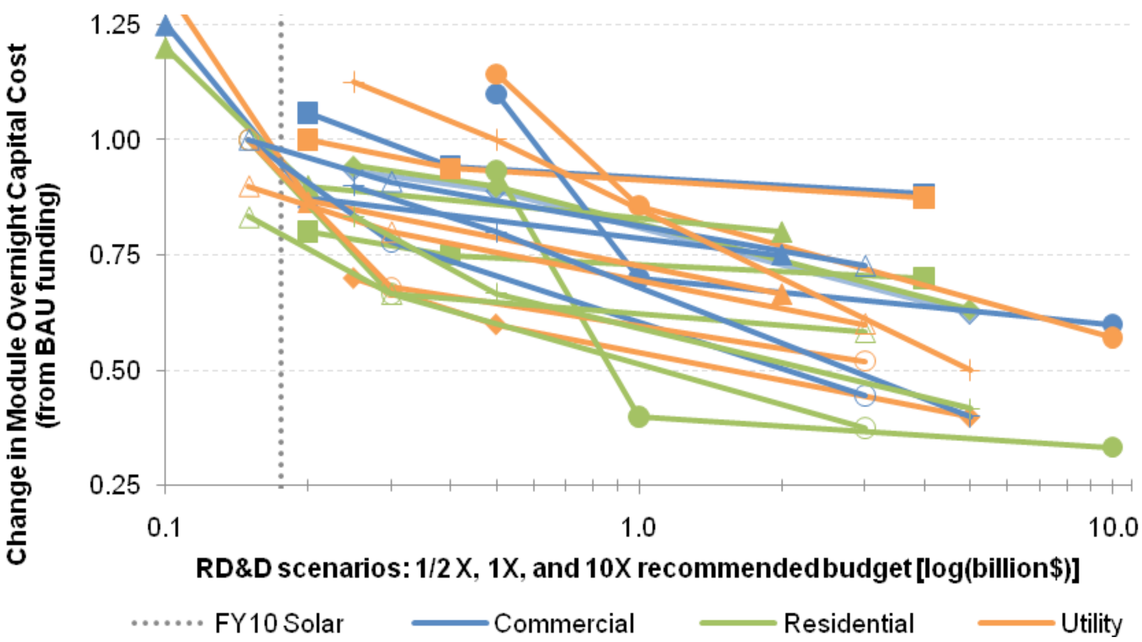


FIGURE A-59. Change in solar PV module overnight capital cost (20,000 ft2) in 2030 compared to BAU funding scenario under each expert's recommended budget, half of recommended budget, and ten times recommended budget. The gray dotted line refers to DOE FY 2010 budget for PV, system integration, and market transformation, $175 million.

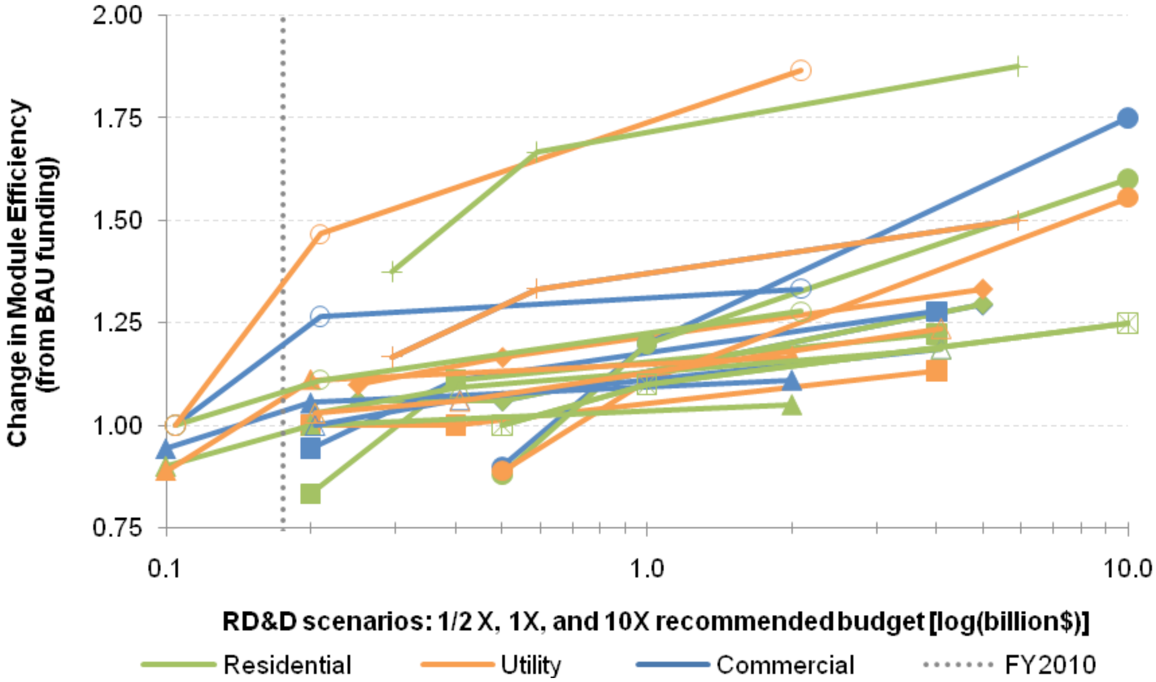


FIGURE A-60. Change in solar PV efficiency in 2030 compared to BAU funding scenario under each expert's recommended budget, half of recommended budget, and ten times recommended budget.

A.8. Uncertainty ranges of experts

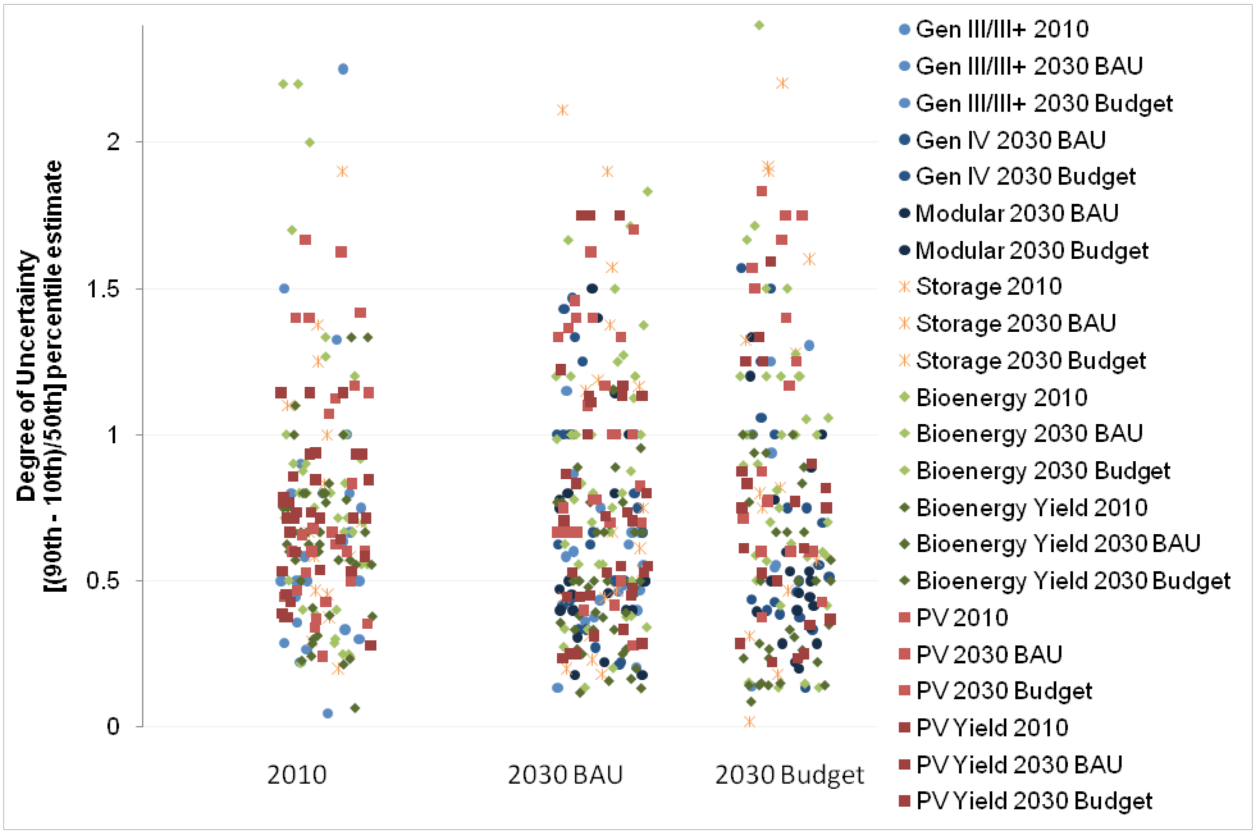


FIGURE A-61. Degree of uncertainty for estimates of cost (and yield or efficiency, where applicable) in 2010, under 2030 BAU funding, and under 2030 recommended budgets across all technologies.

A.9. Longitudinal correlation matrices

	index	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	tech code	GTC	DTC	JTC	ETC	COL	GAS	CCS	GCC	GBC	DBC	CAS	BLI	BNS	FLO	BEV	CAR	HYB	PEV	FCV	THR	FOR	MOD	PVR	PVC	PVU
Cross-Tech Correlation	GTC	**1.00**	0.95	0.95	0.70	0.60	0.60	0.70	0.70																	
	DTC	0.95	**1.00**	0.95	0.70	0.60	0.60	0.70	0.70																	
	JTC	0.95	0.95	**1.00**	0.70	0.60	0.60	0.70	0.70																	
	ETC	0.70	0.70	0.70	**1.00**	0.70	0.70	0.65	0.65																	
	COL	0.60	0.60	0.60	0.70	**1.00**	0.70	0.90	0.70																	
	GAS	0.60	0.60	0.60	0.70	0.70	**1.00**	0.70	0.90																	
	CCS	0.70	0.70	0.70	0.65	0.90	0.70	**1.00**	0.80																	
	GCC	0.70	0.70	0.70	0.65	0.70	0.90	0.80	**1.00**																	
	GBC									**1.00**	0.70															
	DBC									0.70	**1.00**															
	CAS											**1.00**														
	BLI												**1.00**	0.50	0.30	0.50	0.10	0.10	0.50	0.10						
	BNS												0.50	**1.00**	0.50	0.30	0.10	0.30	0.30	0.05						
	FLO												0.30	0.50	**1.00**	0.30	0.10	0.30	0.30	0.05						
	BEV												0.50	0.30	0.30	**1.00**	0.50	0.70	0.90	0.40						
	CAR												0.10	0.10	0.10	0.50	**1.00**	0.70	0.70	0.40						
	HYB												0.10	0.30	0.30	0.70	0.70	**1.00**	0.80	0.40						
	PEV												0.50	0.30	0.30	0.90	0.70	0.80	**1.00**	0.40						
	FCV												0.10	0.05	0.05	0.40	0.40	0.40	0.40	**1.00**						
	THR																				**1.00**	0.60	0.70			
	FOR																				0.60	**1.00**	0.60			
	MOD																				0.70	0.60	**1.00**			
	PVR																							**1.00**	0.95	0.90
	PVC																							0.95	**1.00**	0.92
	PVU																							0.90	0.92	**1.00**

TABLE A-15. Cross-technology correlation matrix. GTC: gasoline-substitute from biomass or a mixture of biomass and coal through thermochemical conversion pathways; DTC: diesel-substitute from biomass or a mixture of biomass and coal through thermochemical conversion pathways; JTC: jet fuel-substitute from biomass or a mixture of biomass and coal through thermochemical conversion pathways; ETC; electricity from biomass or a mixture of biomass and coal through thermochemical conversion pathways; COL: coal power without carbon capture and storage; GAS: combined cycle natural gas power without carbon capture and storage; CCS: coal power with carbon capture and storage; GCC: combined cycle natural gas power with carbon capture and storage; GBC: gasoline-substitute from biomass through a biochemical conversion pathway; DBC: diesel-substitute from biomass through a biochemical conversion pathway; CAS: compressed air energy storage; BLI: utility-scale lithium-ion-based batteries; BNS: utility-scale sodium-sulfur-based batteries; FLO: utility-scale flow batteries; BEV: light-duty battery electric vehicles; CAR: light-duty advanced internal combustion engine vehicles; HYB: light-duty hybrid vehicles; PEV: light-duty plug-in hybrid vehicles; FCV: light-duty fuel cell vehicles; THR: Gen III/III+ nuclear power; FOR: Gen IV nuclear power; MOD: small and medium factory-built nuclear power; PVR: residential photovoltaic solar power; PVC: commercial photovoltaic solar power; PVU: utility photovoltaic solar power.

Technology code	Time correlation between 2010 and 2030
GTC	0.9
DTC	0.9
JTC	0.9
ETC	0.8
COL	0.9
GAS	0.9
CCS	0.9
GCC	0.9
GBC	0.9
DBC	0.9
CAS	0.7
BLI	0.9
BNS	0.8
FLO	0.8
BEV	0.9
CAR	0.7
HYB	0.8
PEV	0.9
FCV	0.9
THR	0.7
FOR	0.9
MOD	0.8
PVR	0.9
PVC	0.9
PVU	0.9

TABLE A-16. 2010 and 2030 longitudinal correlations for each technology. See caption for TABLE A-15 for technology code definitions.

A.10. Energy Prices in the MARKAL model

Energy prices are determined endogenously in the model. US fossil fuel supply (coal, natural gas, and oil) is described by a set of supply curves relating production amounts to market prices. These interact with import price curves to set the market clearing price for each energy carrier. The model will pick the lowest cost supplies "first" and add new resources until supply equals demand. The market clearing energy price is thus equal to the marginal cost, the cost of producing one more unit. Biomass prices are determined in the same manner as fossil fuel prices, but there is no competition from imports. The price levels of these fuels are calibrated to match the price assumptions in the AEO.

The electricity price formation is a more complex process. While the concept of marginal cost pricing is still used the underlying mechanics are more intricate. Since power stations are described by their investment and operating costs as well as their performance characteristics several components influence the price level. In addition to investment costs and running costs other factors such as fuel costs, heat rates, and operating regime of power stations determines the economics of generation. To complicate matters further, prices will vary by season and time of day and there is also a capacity market to ensure system reliability. Since the requirements for available capacity and for supplying a varying load across seasons and time of day has to be met by the same generation assets, the competition between different generation technologies can depart significantly from what a straight comparison of levelized costs would suggest. For example; a flexible and dispatchable technology with high availability such as a natural gas turbine might be the preferred investment option even if a wind turbine has a lower expected levelized cost. The benefits from the higher value the natural gas turbine achieves in the capacity market along with its ability to reliably supply electricity during peak hours when the value of the electricity is the highest can outweigh the higher average generation costs.

Like electricity prices the prices for liquid fuels are determined by the interaction of the technologies that produce them as well as the cost of the input feedstocks. Liquid fuels however, are not subject to time-of-use pricing and capacity markets which makes the price formation process less complex than for electricity. Marginal cost pricing is still used and most fuels will be priced at the crude oil price plus a cost of upgrading the crude oil (refinery margin) to the fuel in question. Alternative fuels such as corn ethanol, biodiesel or other advanced bio- and synthetic fuels are also available and will impact the pricing of marketed fuels.

A.11. Interdisciplinary research

A.11.1. Bioenergy

The experts consulted stressed the importance of supporting interdisciplinary research and technology areas related to developing and using bioenergy. For these related technology areas, or "other" research, they highlighted the need to further develop biochemical technologies, transportation technologies that can use liquid fuels that are not perfect substitutes for conventional fuels, fossil fuel refining and conversion technologies, and feedstock genetics, harvest, and transport. Experts identified the need to further develop: microbiological technology (e.g., for the fermentation of lignocellulosic biomass), biomass pretreatment processes, enzymes, (e.g.,ethanologens, and enzyme-based transesterification), and the production of carbohydrate omega-3 oils from biofuel byproducts. Experts also identified the need to support research in feedstock transportation, land use changes, and life-cycle emissions associated with biomass to reduce the uncertainties related to the cost and environmental impacts of bioenergy technologies. Several of the experts were concerned that feedstock RD&D funded by the U.S. Department of Agriculture was insufficient and that the private sector would not address feedstock research needs. They specifically stated that cellulosic feedstocks and algae should be emphasized, that plant genetic engineering should continue to be explored, and that better harvesting methods are needed. Experts who recommended increasing the support for feedstock development insisted that feedstock issues would dominate the scale, cost, and environmental impact of bioenergy technologies.

Eight out of ten experts indicated that there should be coordination between fossil-to-power or fossil-to-liquid fuels and biomass-to-power or biomass-to-liquid fuels research. Specific technologies that they recommended for exploring joint work with fossil and biomass feedstocks were: combustion, co-gasification, hydrotreating (hydro-deoxygenation), gasification (high pressure, entrained flow), liquefaction, catalytic reforming, and solvent-based extraction, Fischer-Tropsch, separations, crude upgrading, and hydrothermal processing. One expert took the analogy of thermochemical research for bioenergy and fossil fuels one step further by stating that regardless of the research, carbon emissions are still a concern and said, "The whole gasification+conversion for syngas to liquids or electricity are the same. Increases in efficiency of process unit operations must be pursued regardless of feedstock. Technoeconomic analysis is key for all (developing better process models) to distinguish between technological alternatives."

Several experts voiced concerns over what one of them termed "institutional stove-piping", which they claimed was the U.S. Department of Energy thinking in black and white terms regarding thermochemical v. biochemical research, fossil v. bioenergy research thus stifling innovative and interdisciplinary discoveries.

A.11.2. Energy Storage Technologies

Experts responded with many technologies that could be concurrently developed with utility-scale energy storage technologies. These include vehicle technologies in the transportation sector, particularly electric vehicle technologies and fuel cells, concurrently with batteries, flow batteries, and electrochemical capacitors. Flywheels for energy storage could have overlap with industrial applications. Personal mobility storage, distributed storage, and residential thermal storage could also be developed in parallel. An added benefit of improving residential thermal storage is improvement in building cooling technology and efficiency. Many experts also cited strong overlap with smart grid technologies and systems and efforts to improve grid operations, especially at the substation level and for cyber security. Un-interruptible power supply (UPS), power conversion, and semiconductor switching were other areas of overlap. Heat exchangers and gas compressors, e.g., for industrial gases, overlapped with CAES development. Mining equipment improvements and other battery chemistries like advanced lead acid should also be developed alongside batteries for utility-scale storage.

The major factors affecting experts' uncertainty about mutual research were differences in desired technical attributes, like energy density, lifetime or duration of storage, cost, size, scale. Many of these attributes speak to the differences between the transportation vehicle applications and grid-scale applications. One expert recommended a separate line item for energy storage so that RD&D funding is not overtaken by smart-grid and PHEV interests. A few experts had no uncertainty.

Many experts responded that there should be interdisciplinary research between storage technologies and transmission and distribution technologies. Experts noted that storage technologies could radically change transmission and distribution system planning needs. This potential needs to be studied through production cost models and mapped in order to reflect the system benefits of storage and make the most optimal investments. Better understanding is needed through improved economic dispatch or market models, and models of load flows (e.g. storage as a sink) and transmission dispatch (e.g. storage as a transmission service) where storage is an integral component of the system. Such studies could show how transmission and distribution assets can be sized to average load rather than peak demand, or how existing resources can be better utilized, when storage is available, perhaps resulting in cost savings. This would help anticipate storage-supported, dispatchable wind and solar power. The integration of storage and renewables, on both the grid-level and distributed systems, needs to be demonstrated, especially if there are concerns about system operation constraints. Other areas of research needed are in electricity market and utility regulation, control technologies, ramp rates, and superconducting lines for SMES, and the constraints caused by local storage.

A.11.3. Nuclear

Most experts highlighted the importance sensors, digital information and communications technology, prognostics, diagnostics, and system wide modeling as interdisciplinary technology areas that are very important to the field of nuclear energy. In particular, experts mentioned the importance of advanced digital systems for safety, and remote real-time monitoring of reactors and fuel cycle facilities. The improvement of manufacturing technologies and the reduction in the size of components to allow factory construction of complete units were also mentioned by many experts as important for the future of nuclear power.

Experts also emphasized the need to fund anticipatory research at the U.S. Nuclear Regulatory Commission, so that the regulatory basis for licensing Gen IV reactors can be developed in parallel with DOE RD&D. A couple of experts felt that Thorium fuel cycles (while partially included in current programs) could be more fully addressed. Similarly, some expressed the need to fund (or at least track the progress off) the Th-U233 fuel cycle, which is being conducted in other countries needs to at least be tracked.

The licensing of coupled desalination systems that improve economics and waste heat utilization; of high efficiency dry cooling applications (siting of nuclear and other thermal technologies will be limited by consumptive water use constraints); and of close coupled siting conditions and requirements for industrial site applications was also mentioned as an area that needs to be funded. The integration of MOX fuels into the U.S. regulatory system was also discussed.

A.11.4. Fossil

Experts gave mixed responses on their outlook for the applicability of carbon capture technologies to be applied to biomass-fired plants. Of the experts who were supportive of this type of interdisciplinary research, several experts highlighted the potential role for CCS with biomass combustion (in combination with fluidized bed combustion, chemical absorption, and oxy-fired combustion).

Experts also highlighted the potential for CCS technologies to impact industrial sectors other than electric power. Repeatedly, experts bought up the refinery, petrochemical, chemical, and industrial gas sectors as important industries that could serve as early testing grounds for CCS technologies. In particular, experts noted that these industries are already comfortable with chemical processes similar to those needed for CCS, in particular IGCC and oxy-combustion technologies. A few experts also suggested that the cement and steel industries could also be important sectors for co-developing CCS technologies. One expert suggested that technologies for reservoir geophysics, drilling technologies, modern membranes, advanced high-temperature materials, and pre-fabrication / modularization could push additional important breakthroughs for CCS.

A.11.5. Buildings

Experts were not asked about interdisciplinary areas of research regarding buildings.

A.11.6. Vehicles

Experts were not asked about interdisciplinary areas of research regarding light duty vehicles.

A.11.7. Solar PV

Experts cited the following areas that could benefit from research in PV technologies: high efficiency lighting and displays; wafer lift-off processes; low cost single crystalline substrates; spectral splitting optical components; power electronics for servers, appliances, EVs, wind turbines; microelectronics; and energy storage and smart grid infrastructure. The experts agreed in general that technology challenges in PV are very different than in telecommunications and semiconductors, especially beyond the applied research stage, because PV is exposed to harsh environmental conditions for decades and generates a low-cost commodity, namely electricity, from a diffuse energy source.

Chapter 4 Appendix

A4.1. Database on Department of Energy Assistance

A4.1.1. Data Description

Several data sources exist for R&D support, although they all have limitations. The "R&D Database" is maintained by the Office of Science and Technology Information (OSTI), part of the DOE Office of Science (DOE, 2009b). This database is composed of filed summary sheets, which have limited information, and the only summary statistic available is the number of projects. Budget activity, start and end dates are often incomplete, and many sheets have little or no description.[1] Limiting the count to those projects with consistent start and completion dates, the R&D Database records in FY 2008 indicate that there were 4,898 active awards, including 948 cooperative agreements, 3,906 grants, and 44 activities that fall under other mechanisms. We found that 1,238 awards were sponsored by a DOE office active in ERD&D (EERE, EDER, Fossil or Nuclear), and 3,475 by DOE's Office of Science. This reflects the fact that the working model of the Office of Science is mainly through university grants.[2] A limitation of this database is that total budgets for technology areas or mechanisms cannot be determined, because there is no way to aggregate information in the R&D Database.

The DOE's Office of Management maintained a separate database that contained information on R&D support activities, the Procurement and Assistance Date System (PADS) (DOE, 2009a). PADS contained data on funding and number of awards by office, site, or Catalog of Federal Assistance Codes (CDFA), but it includes only currently active items with a value over $25,000. On 6 March 2009, 5,290 assistance items were active, funded at $525 million in current FY obligations. Of these, 1,064 were cooperative agreements, worth $297 million in the current fiscal year. Of the total assistance items, 1,494 of all types worth $216 million have CDFAs that are used to fund ERD&D (for example, not including the Office of Science). From these figures, one can surmise that approximately 56% of DOE's assistance investments are in ERD&D; 41% of its investments are in mechanisms that are close to a partnership, versus a transaction; the intersection of these two groups—something less than $216 million—would make up the size of DOE's ERD&D partnership effort. Because PADS included only active awards, it measured less than the full year's investment. The PADS system was also used to produce the annual Procurement and Financial Assistance report (DOE, 2008), which does show the full size of the investment in each agreement, but does not discern ERD&D in current year obligations. This report includes a breakdown by

1 Of 20 random summary sheets active in 2008 examined, only one had the "Project Description" field completed, 5 were missing budget and recording data for 1 or more active years, and 5 were active past their "Project end date" (not counting those that had post-completion budget corrections).

2 (DOE, 2009b) records in FY 2008, Office of Science: 3,148 grants vs. 153 cooperative agreements; EERE, EDER, Fossil or Nuclear: 477 grants vs. 753 cooperative agreements.

total obligation over the life of the award, rather than current fiscal year obligation, but this is even less useful for measuring partnerships for ERD&D.[3] In 2010, PADS was no longer accessible to the public; the former website directs visitors to *USA Spending*.

An external database intended for other purposes is more useful for tracking ERD&D than DOE's own systems. *USA Spending* is a public disclosure project established by the Federal Funding Accountability and Transparency Act of 2006 (S. 2590) (Transparency Act, 2006). This Act mandates disclosure of Federal contracts and assistance (but not wages and salaries) by OMB, which maintains a database accessible online (OMB, 2010). Fewer unique items are recorded in *USA Spending* than in DOE's databases (4,128 assistance awards in *USA Spending*, vs. 4,898 in R&D database and 5.933 in PADS for FY 2008). It is not clear how well double-counting is eliminated in the DOE systems, or whether the *USA Spending* database includes all projects, thus the discrepancy could come from either or both of these factors. A comparison between different data is shown in table A4.1. The data in *USA Spending* include project descriptions, recipient names, categories, and locations, Federal and non-Federal expenditures, and budget and program codes so that detailed trends can be analyzed.

USA Spending includes both contract and assistance databases; the actions of interest to ERD3 are all in the assistance section. Each entry in *USA Spending* is linked to a particular "award"—a grant or cooperative agreement or other mechanism—and all entries for the same award are linked by unique Federal Award ID number. In the decade from 2000 through 2009, 62,932 transactions are recorded in 22,947 unique awards. For the analysis here, only those awards which were active at some point in that period (21,326) are included; the remaining were financial adjustments to completed projects. Catalog of Federal Domestic Assistance (CFDA) codes are used to categorize projects as ERD&D, Science, or other programs as follows:

(i) All DOE codes are 81.xxx;

(ii) The last three digits that correspond to ERD&D are: 007, 036, 057, 078, 079, 080, 086, 087, 089, 096, 105, 107, 111, 119, 121, and 122 (2005 and later only),

(iii) The last three digits that correspond to Science are 048, 049 and 122 (pre 2005), and

(iv) All other codes, including defense activities, environmental management, and conservation deployment subsidies, are grouped as "Other".

Table A4.2 summarizes the data in *USA Spending* awards by year, for various categories of awards. The funding amounts are shown in millions of current un-deflated dollars, directly calculated from the database; the GDP deflation factor used to 2010 constant dollars is also shown.

3 At the end of FY 2008, there were 5,933 awards worth $25.5 billion; during the course of the year 6,150 awards had current obligations, representing $2.7 billion. Mechanisms are listed for those awards active at the end of the fiscal year: 1,232 active cooperative agreements worth $14.7 billion, 142 formula grants worth $1.8 billion, 4,504 project grants worth $8.1 billion, and a few miscellaneous actions (DOE, 2008).

	Per Annual PADS reports				Per USA Spending			
FY	Cooperative Agreements	Project Grant	Formula Grant	Obligation ($million)	Cooperative Agreements	Project Grant	Formula Grant	Obligation ($million)
2004	1,801	4,540	138	2,036	1,244	3,378	150	2,077.7
2005	1,692	4,687	139	2,199	1,206	3,570	136	2,233.3
2006	1,454	4,783	146	2,246	1,013	3,257	129	2,139.3
2007	1,316	4,524	128	2,253	856	3,139	143	2,280.9
2008	1,232	4,504	142	2,741	784	3,152	131	2,176.3

TABLE A4.1. Assistance in DOE vs. OMB databases. Source: USAspending.gov, DOE (2008, 2004, 2006, 2007)

	Fiscal Year										Total
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	
Deflator to 2010$	0.7779	0.7975	0.8106	0.8319	0.8557	0.8873	0.9189	0.9447	0.9793	0.9839	
Awards											
Total	4,156	4,230	4,588	4,786	4,790	4,934	4,447	4,167	4,170	6,367	21,326
ERD&D	866	884	1,218	1,289	1,220	1,296	1,018	879	960	1,121	5,648
Science	2,477	2,602	2,580	2,642	2,775	2,849	2,831	2,745	2,683	3,127	10,601
Million current dollars:											
Funding for awards											
Total	$1,559	$1,630	$1,877	$1,892	$2,078	$2,233	$2,139	$2,281	$2,213	$13,720	$31,623
ERD&D	$395	$414	$518	$573	$597	$671	$689	$961	$846	$1,515	$7,179
Science	$719	$784	$817	$796	$979	$1,004	$968	$863	$833	$1,367	$9,130
By mechanism:											
Cooperative Agreement	$602	$632	$720	$731	$846	$914	$860	$1,160	$893	$1,470	$8,827
Project grant	$782	$806	$876	$862	$953	$1,034	$986	$866	$987	$3,322	$11,474
Formula grant	$169	$176	$267	$287	$272	$278	$280	$250	$266	$8,903	$11,149
Direct payment	<$0.1	0	0	0	0	0	0	0	0	<$0.1	<$0.1
Other types	$5.6	$17.4	$14.0	$11.0	$6.6	$7.4	$13.6	$5.2	$66	$26	$173
By recipient:											
Small business	$153	$171	$198	$188	$182	$197	$206	$200	$209	$288	$1,991
Other business	$216	$200	$245	$267	$341	$401	$389	$485	$526	$1,038	$4,108
Government	$285	$289	$400	$408	$382	$383	$379	$334	$357	$10,488	$13,706
Higher education	$709	$771	$822	$820	$897	$1,010	$928	$849	$954	$1,501	$9,261
Individuals	$0.4	$0.1	$0.6	$0.3	$0.8	$0.8	$0.4	$0.3	$0.1	$0.2	$4
Nonprofits	$178	$174	$164	$173	$252	$211	$203	$176	$140	$269	$1,939
Non-federal funding											
Total	$1,287	$866	$912	$1,172	$1,643	$2,173	$5,486	$1,723	$1,795	$3,881	$20,938
ERD&D	$511	$357	$419	$468	$756	$984	$2,697	$764	$764	$1,801	$9,521
Science	$42	$30	$12	$23	$17	$49	$8	$2	-$4	$6	$184

Table A4.2. Awards and funding from the USA Spending database

A4.2. DATA COLLECTION INSTRUMENTS

A4.2.1. Screening Instrument

You are being asked to participate in a study being conducted by the ERD3 Project within the Kennedy School at Harvard University. The purpose of the study is to measure the use of, and investments in, energy technology innovation by the nation's private sector.

Energy technology innovation describes a wide range of activities related to using, conserving, generating, or storing energy. Some of these technologies are used beyond, and come from beyond, what would be called the "energy industry." Clearly, energy technology is important, yet there is little information on innovation in energy technology in business and industry. Thus, it is very difficult to determine how best to encourage it.

Participating in the study is easy. We ask that you fill out the enclosed questionnaire and return it to us within the next two weeks. **We expect that it will require less than 10 minutes of your time.** If someone else in your organization is more knowledgeable concerning the questions that we ask, please forward this questionnaire to that individual.

Your establishment was selected for this study by means of a scientific process designed to yield a sample of businesses that is nationally representative of certain industries in the nation's private sector. **We realize that your establishment may not have any role in energy technology innovation – your response is still important to us.**

The data for this study are being collected for us by Westat, a research company in Rockville, Maryland. Westat is required to protect the privacy of all information collected. Under no circumstances will information collected in this study be released in a form that reveals personal or business information, or allows for the identification of individuals or businesses. The information collected in this survey will be used only for statistical estimates and descriptions of energy innovation activity.

Of course, your participation in this study is voluntary. However, the validity of the study results depends on a high response rate among sampled establishments.

Thank you in advance for your participation. If you have any questions, please contact the Westat study manager, Jeff Kerwin, at jeffreykerwin@westat.com, or 301-517-4028. You may also communicate with me directly, at Charles_Jones@hks.harvard.edu, or 617 -496 -0041.

Sincerely,

Charles Jones, Ph.D.

We would like to know about this establishment and its activities.

Please note that:

- An establishment is generally a single physical location where business is conducted or where services or industrial operations are performed. We realize that your company may have multiple locations. Any of your locations could have been sampled for this project.
- Even if the one location addressed in this survey may not represent your entire company, please answer the questions as they relate to this establishment only; the locations sampled for the project will be representative of establishments across the nation.
- When considering this establishment's activities, please include work performed onsite, funded through this establishment's budget, or directed by its management.

For this study, we randomly sampled the establishment based at this address:

[- PRINT ADDRESS HERE -]

Section A: Energy-Related Activities

A1. Please indicate whether or not this establishment conducts, funds, or directs each of the following activities:

		Yes	No
A.	Provide energy resources or services (such as extraction, refining, generation or delivery)?	☐	☐
B.	Design or manufacture energy equipment—that is, equipment for providing energy services (such as extraction, refining, generation or delivery), or for managing energy resources (such as storage or conservation)?	☐	☐
C.	Produce materials, components, or capital goods for customers that either provide energy services or manufacture energy equipment?	☐	☐
D.	Use significant amounts of energy in its operations, such that sources or costs of energy are important for management decisions?	☐	☐
E.	Design or manufacture products that use energy such that customers may consider reducing energy use an important feature?	☐	☐

F. Provide R&D or engineering services for customers that provide energy services, equipment or components, or that seek to reduce the energy consumption of their products? ☐ ☐

G. Provide consulting services for customers that use significant amounts of energy, to help them reduce or better manage their energy use? ☐ ☐

Section B: Innovation Activities

B1. Does <u>this</u> establishment conduct, fund, or direct any innovation activities (such as research, development, product or process improvement, pilot or scale-up facilities)?

- ☐ Yes
- ☐ No

B2. Does <u>another</u> establishment within your company conduct, fund, or direct any innovation activities (such as research, development, product or process improvement, pilot or scale-up facilities)?

- ☐ Yes
- ☐ No
- ☐ Does not apply – this is the company's sole establishment

B3. Are innovations resulting from activities <u>external</u> to your company (for example, universities, other companies, national laboratories, etc.) important for this establishment's business operations?

- ☐ Yes
- ☐ No

Section C: Innovation Activities and Energy

C1. Did you answer at least one "yes" in BOTH section A and B?

- ☐ Yes
- ☐ No → **Skip to Section D**

C2. Are any of the innovation activities you reported in Section B related to the energy activities reported in Section A?

- ☐ Yes
- ☐ No

Section D: About your Establishment

D1. Which of the following best describes this establishment?

- ☐ Independent business → **Skip to Question D4**
- ☐ Subsidiary, division, or establishment of a larger company
- ☐ Division or business unit headquarters within a larger company
- ☐ Company headquarters
- ☐ Other type of entity (please specify):____

D2. Is this establishment made up of multiple divisions or business units within your company?

- ☐ Yes
- ☐ No

D3. Is this establishment primarily engaged in providing management or services to other establishments of your firm (rather than for the general public or other business firms)?

- ☐ Yes → What is the principal kind of business performed by the firm that is managed or serviced by this establishment? (If more than three kinds of business, just list the three most important)

  ____

  ____

  ____

- ☐ No

D4. According to our records, the North American Industry Classification System (NAICS) code for this establishment is [- PRINT HERE -]. Is this correct?

- ☐ Yes

☐ No → What is the correct NAICS code? ______________________________

☐ Do not know

D5. Is this establishment a "start-up", with operations primarily funded by investment capital rather than revenue?

☐ Yes → To date, how much capital has been raised? $ __________________

☐ No

D6. How many employees worked at this establishment at the end of the most recent fiscal year?

☐ 5 or fewer

☐ 6 to 20

☐ 21 to 50

☐ 51 to 100

☐ 101 to 250

☐ 251 to 500

☐ More than 500

D7. For the most recently ended fiscal year, what was the total volume of business for <u>this</u> establishment—in terms of either revenue or operating budget (whichever best applies)?

$__________________ revenue OR $ _________________ operating budget

D8. What percentage of this establishment's total revenue (or operating budget, if applicable) was derived from or dedicated to the energy-related activities reported in Section A, Question 1?

☐ Does not apply - answered "no" to all of the items in Section A

☐ Less than 20%

☐ 20% to less than 40%

☐ 40% to less than 60%

☐ 60% to less than 80%

☐ 80% or more

D9. If you have any additional comments about the topics covered in this questionnaire, please share them with us:

____

____

____

Thank you. Please return your completed survey to us in the envelope provided. If the envelope has been misplaced, mail your survey to:

Jeff Kerwin
Westat
1600 Research Blvd.
Rockville, MD, 20850

Depending on your answers, we may follow up with you to learn more about your establishment's activities with respect to energy and innovations.

A4.2.2. Follow-up Instrument

Section A: Your Establishment's Investments in Energy Innovation

You previously told us that your establishment conducts or funds innovation activities (that is, research, development, testing, product or process improvement) related in some way to energy. As such, you are of special interest for this study. We would appreciate learning more about these activities.

Please note that the questions below address only your establishment.

- An establishment is generally a single physical location where business is conducted or where services or industrial operations are performed. We realize that your company may have multiple locations. Any of your locations could have been sampled for this project.
- Even if the one location addressed in this survey may not represent your entire company, please answer the questions as they relate to this establishment only; the locations sampled for the project will be representative of establishments across the nation.
- When considering this establishment's activities, please include work performed onsite, funded through this establishment's budget, or directed by its management.

For this study, we randomly sampled the establishment based at the location:

[PRINT PHYSICAL ADDRESS HERE]

A1. Are innovation activities (such as research, development, product or process improvement, pilot or scale-up facilities) related to energy a normal part of business at this establishment, or are these activities only part of special projects or special programs?

- ☐ Normal part of business
- ☐ Only part of special projects or programs → **Skip to question A7**
- ☐ Neither – innovation important to us is funded or conducted by others → **Skip to section B**

A2. During 2009, what were the total expenses for innovation activities (such as research, development, product or process improvement, pilot or scale-up facilities) at your establishment? Please consider expenses for all innovation activities at this establishment, regardless of whether they were related to energy.

☐ Less than $200K	☐ $50 mil to less than $100 mil
☐ $200K to less than $500K	☐ $100 mil to less than $250 mil

☐ $500K to less than $1 million (mil)	☐ $250 mil to less than $500 mil
☐ $1 mil to less than $5 mil	☐ $500 mil to less than $750 mil
☐ $5 mil to less than $20 mil	☐ $750 mil to less than $1 billion
☐ $20 mil to less than $50 mil	☐ $1 billion or more

A3. Of the amount you reported above, please estimate what percentage was devoted to each of the following types of innovation activities:

		Percentage
a.	Improving our own energy resources or services (such as extraction, refining, generating, or delivery)	________%
b.	Improving energy equipment or components that we design or manufacture – that is, equipment or components for providing energy services or for managing energy resources	________%
c.	Improving equipment or practices in order to reduce our own energy use	________%
d.	Improving or developing products that we design or manufacture in order to reduce customers' energy use	________%
e.	Technical or R&D services for customers that provide energy resources, services, equipment, or components, or that seek to reduce the energy consumption of their products	________%
f.	Technical or consulting services for customers that use significant amounts of energy, to help them reduce or better manage their energy use	________%
g.	Innovation activities not related to energy	________%
	TOTAL	**100%**

A4. Considering <u>all</u> of your establishment's energy-related innovation activities (indicated in items a-f, in question A3 above) during 2009, approximately what percentage of the funding for these activities came from each of the following sources:

			Percentage
a.	Your own company?		________%
b.	Other companies?		________%
c.	Nonprofit foundation grants or contracts?		________%
d.	Federal government grants or contracts?		________%
e.	State/local government grants or contracts?		________%
f.	Other sources? (please specify)		________%
		TOTAL	**100%**

A5. For the energy-related innovation activity conducted, funded, or directed by your establishment during 2009, approximately what percentage was conducted at each of the following:

			Percentage
a.	Your own establishment?		________%
b.	Other establishments in your company?		________%
c.	Other companies within the U.S.?		________%
d.	Other companies outside the U.S.?		________%
e.	Academic, cooperative, or nonprofit research facilities		________%
f.	Government research facilities		________%
		TOTAL	**100%**

A6. For each category below, please indicate whether or not it describes any of the energy-related innovation activity conducted, funded, or directed by your establishment during 2009:

		Yes	No
a.	Basic or applied research	☐	☐
b.	Technology development	☐	☐
c.	Pilots or field demonstrations	☐	☐
d.	Initial commercial-scale activities	☐	☐

e.	Product design/improvement	☐	☐
f.	Process design/improvement	☐	☐
g.	Technology search or evaluation	☐	☐
h.	Intellectual property management	☐	☐

→ **Please skip to question A10 on the next page**

A7. In what fiscal year(s) was your most recent special or one-time energy-related innovation project?

____

A8. What was the approximate cost of this project?

$ _________________ Your best estimate is fine.

A9. What was the purpose of this project?

(Examples: To save on energy costs, to develop new product)

____

A10. In what areas or sectors of energy do your innovation activities occur? Select all that apply.

- ☐ Coal
- ☐ Oil
- ☐ Natural gas
- ☐ Wind
- ☐ Solar
- ☐ Biomass
- ☐ Nuclear
- ☐ Waste to energy
- ☐ Electric generation
- ☐ Power transmission and distribution
- ☐ Energy efficient buildings
- ☐ Energy efficient appliances
- ☐ Energy efficient industrial processes
- ☐ Efficient or alternative-fuel vehicles
- ☐ Energy storage
- ☐ Instruments, sensors, and controls
- ☐ Other area (please specify):

A11. How does your establishment evaluate the financial impact of its R&D costs or other investments in energy-related innovation?

- ☐ Decided by others – our costs/investments are completely covered by funding from outside sources, or will be recouped by other establishments in our company
- ☐ Not formally measured – this innovation is intended to benefit our customers/clients
- ☐ We expect costs/investments to be recouped within ____________ years
- ☐ We expect recent innovations to account for at least ____________ percent of revenue
- ☐ We expect productivity, revenue per unit energy, or cost savings to improve at least __________ percent per year
- ☐ Other evaluation method (please specify): ________________________________

A12. Which of the following best describes the scope of activity you considered when answering questions in this section?

- ☐ All relevant activity conducted at, funded by, or directed by this location only
- ☐ Only part of the relevant activity conducted at, funded by, or directed by this location —there are other divisions or functions at this location for which I cannot report
- ☐ Activities of this location and other locations as well—representing all of the relevant activity within our company
- ☐ Activities of this location and other locations as well—but representing only part of the relevant activity within our company

Section B: Processes of Innovation in Your Industry

When answering the questions in this section, please try to consider the broad range of energy activities in your industry (supply, end use, conservation, etc.) .

B1. In the list below, please indicate the three most important <u>sources of information</u> for decisions about investing in energy-related innovation in your industry. Enter a "1" for the most important, "2" for the second most important, and "3" for the third most important:

__ Internal company resources

__ Supply chain sources (such as suppliers, customers, clients, etc.)

__ Industry sources (such as trade associations, competitors)

__ Consultants and private R&D organizations

__ Institutional sources (such as government, academia, public research institutes)

__ Energy costs

__ Other sources (please specify): ____

B2. In the list below, please indicate what you believe to be the three most important <u>origins of energy-related innovation</u> within your industry. Enter a "1" for the most important, "2" for the second most important, and "3" for the third most important:

__ Research conducted within our company

__ Research conducted by other companies in our industry

__ Research conducted by national laboratories or other government work

__ Research conducted at universities or other academic work

__ Innovations adopted from other industries

__ Cross-pollination between industries producing new ideas

__ Other origins (please specify): ____

B3. Please indicate the three factors below that you believe have been the most important for promoting energy innovation within your industry. Enter a "1" for the most important, "2" for the second most important, and "3" for the third most important:

__	R&D tax credits	__	New markets
__	Government R&D grants or support	__	Industry leaders
__	Project loan guarantees	__	Customer tax credits or rebates
__	University research	__	Energy prices
__	National laboratory research	__	Cost-cutting opportunities
__	Inter-firm partnerships	__	Reducing environmental impact
__	Production tax credits	__	Other factors (please specify):
__	Investment tax credits		____________________________
__	Energy portfolio standards		____________________________
			____________________________

B4. Which of the following factors do you believe have been the most challenging for energy innovation within your industry? Enter a "1" for the most challenging, "2" for the second most challenging, and "3" for the third most challenging:

__	Lack of basic science research	__	Difficulty of benefiting from IP
__	Basic science is not yet mature	__	High commercialization cost
__	Lack of qualified personnel	__	Long time from technology to market
__	Supply chain is not yet mature		
__	High cost of R&D	__	Low or uncertain demand
__	Difficulty of financing R&D	__	Regulatory hurdles
__	Long R&D time horizon	__	Other challenges (please specify):
__	Unpredictability of outcomes		____________________________
__	Difficulty of establishing intellectual property		____________________________
			____________________________

B5. Which of the following fields do you believe are producing energy innovations having the most positive impact on your industry? Enter a "1" for the most positive, "2" for the second most positive, and "3" for the third most positive:

- __ Physical sciences
- __ Materials science
- __ Bio & life sciences
- __ Earth & environmental sciences
- __ Electrical and electronic engineering
- __ Mechanical engineering
- __ Chemical engineering
- __ Fabrication technologies
- __ Information technologies
- __ Systems analysis
- __ Design and modeling tools
- __ Organizational or management sciences
- __ Other fields (please specify):

____

____

____

B6. Below are several potential "trends" in industrial innovation. Please indicate what you think are the three most beneficial trends for energy innovation within your industry. Enter a "1" for the most beneficial, "2" for the second most beneficial, and "3" for the third most beneficial:

- __ Centralization of R&D functions
- __ Outsourcing of R&D functions
- __ Locating R&D near production facilities
- __ Locating R&D near universities or other research sites
- __ Absorbing start-ups
- __ Merging with established innovative firms
- __ R&D cooperation with universities
- __ R&D cooperation with other companies
- __ R&D cooperation with government entities
- __ Product standardization
- __ Product customization
- __ Process improvement
- __ Other trends (please specify):

____

____

____

Section C: About Your Start-Up

You previously told us that this establishment is a start-up. We are especially interested in the role of start-ups in energy-related innovations, so we have a few final questions about your start-up.

C1. How did your start-up originate?

- ☐ A spin-off from a larger company
- ☐ A joint-venture between two or more companies
- ☐ A spin-off from a university or university research project
- ☐ A "garage start-up"
- ☐ Other (please specify): ______________________________

C2. Which of the following were sources of capital for your company operations in 2009? Select all that apply.

- ☐ Founder or angel investment
- ☐ Venture capital
- ☐ Loans
- ☐ Private equity
- ☐ Government grants or support
- ☐ Other sources (please specify): ______________________________

C3. At what stage is your start-up with respect to financing?

- ☐ Seed or angel investor capital
- ☐ First round venture capital
- ☐ Second or later round venture capital
- ☐ Pre-IPO, private equity, or bridge financing
- ☐ Post-IPO, still in expansion
- ☐ Post-buy-out, still in expansion
- ☐ Other stage (please specify): ______________________________

C4. Did your company achieve a funding round or other important milestones during 2009?

Yes → (please specify): ____

No

C5. Approximately what percentage of your total start-up capital has been spent on energy-related innovation activities (R&D, product design, field demonstrations, etc.)?________________%

C6. We would like to know about prior affiliations of your personnel working on energy-related innovation. Considering all of these personnel together, which are the most important sources of personnel contributing to energy-related innovation in your start-up? Please count yourself, if applicable. Enter a "1" for the most important, "2" for the second most important, and "3" for the third most important:

__ New entrants to the workforce

__ University faculty or research

__ National labs or federal research institutions

__ Nonprofit research institutions

__ Companies in the R&D services industry

__ Companies in the same industry

__ Companies in other industries

__ Utilities or energy service companies

__ Other start-ups

__ Other types of organizations (please specify): ____________
____
____

C7. Does your company own any sort of intellectual property (patent issued or pending, copyright, etc.) related to energy innovation?

Yes

No → **Skip to END**

C8. Was this intellectual property generated before or after your start-up?

A4.2.3. Telephone Questionnaire

Hello, may I speak to [TARGET RESPONDENT]? My name is [INTERVIEWER NAME] and I'm calling on behalf of researchers at the Kennedy School at Harvard University. I need just a few minutes of your time to determine whether or not your organization has any involvement in innovative energy technology. It should take less than 10 minutes.

Before I ask the questions, I want to assure you that your answers will be treated as confidential—under no circumstances will we release information with anyone else in a way that identifies you or your business.

Also, please understand that my questions concern only the business establishment located at [ESTABLISHMENT ADDRESS]. We realize your company may have other locations, and your answers might differ depending on location. But this location was randomly chosen for the study. When answering the question, please consider work performed onsite at this location, funded through this establishment's budget, or directed by its management.

Now to the questions…

Q1. We would like to know whether or not this establishment conducts, funds, or directs a number of energy-related activities.

		Yes	**No**	**Ref**	**DK**
A.	First, does this establishment provide energy resources or services, such as extraction, refining, generation or delivery?	1	2	7	8
B.	Does it design or manufacture energy equipment – that is, equipment for providing energy services or for managing energy resources, such as storage or conservation?	1	2	7	8
C.	Does it produce materials, components, or capital goods for customers that either provide energy services or manufacture energy equipment?	1	2	7	8
D.	Does it use significant amounts of energy in its operations, such that sources or costs of energy are important for management decisions?	1	2	7	8
E.	Does it design or manufacture products that use energy such that customers may consider reducing energy use an important feature of the product?	1	2	7	8
F.	Does it provide research and development or engineering services for customers that provide energy services, equipment or components, or that seek to reduce the energy consumption of their products?	1	2	7	8
G.	Does it provides consulting services for customers that use significant amounts of energy, to help them reduce or better manage their energy use?	1	2	7	8

BOX 1

IF Q1A-G = 2, THEN END

ELSE, CONTINUE

Q2. Does <u>this</u> establishment conduct, fund, or direct any innovation activities, such as research, development, product or process improvement, pilot or scale-up facilities?

YES	…………1	
NO	…………2	(GO TO Q3)
REF	…………7	(GO TO Q3)
DK	…………8	(GO TO Q3)

Q3. Are any of these innovation activities related to the energy activities you mentioned this establishment is involved in? (IF NECESSARY: You indicated that this establishment…SHOW TEXT OF ITEMS FROM Q1A-G WHERE =1)

A4.3. Sample

A4.3.1. Sample Definitions

The sample for the *Survey of Energy Innovation* was stratified by specifying a specific number of establishments to be drawn from 34 segments. The segments were defined primarily by the North American Industry Classification System (NAICS) code, with additional specifications as defined below:

> *Seeded Sample*: Companies mentioning innovative activities in energy found through web searching—company websites or posted reports—added to increase positive responses in order to test survey instruments and procedure.
>
> *BNEF Sample*: A simple random sample of firms found in the Bloomberg New Energy Finance database as of 6 April 2010, identified as "VC/PE funded" in the United States (universe = 689).

2-digit	Segment	6-digit NAICS included
21	Energy mining and services	213113, 213112, 213111, 212113, 212112, 212111, 211112, 211111
22	Energy utilities	221111, 221112, 221113, 221119, 221121, 221122, 221210, 221330
23	Energy-related construction	237120, 237130
48	Energy pipelines	486110, 486210
31-33	Energy equipment and products	324110, 324199, 325193, 332410, 333414, 333415, 333611, 334413, 335312
	High use and energy related products	311221, 311311, 311312, 311313, 321113, 321211, 321212, 321213, 321214, 321219, 321911, 322110, 322121, 322122, 322130, 322299, 325110, 325120, 325181, 325182, 325188, 325192, 325199, 325211, 325212, 325221, 325222, 325311, 325312, 326140, 326150, 327211, 327212, 327213, 327310, 327410, 327420, 327993, 331111, 331112, 331312, 331314, 331315, 331411, 331419, 331421, 331422, 331423, 331491, 331492, 331511, 332321, 333132, 333618, 334512, 334513, 335110, 335311, 335313, 335911, 336111, 336112, 336120, 336312, 336322, 336350, 336411, 336412, 336510, 336611
	Other Manufacturing	All other 31xxxx-33xxxx
54	R&D	541710, 541712
	Engineering and environmental	541330, 541620
	Other likely innovation	541380, 541611, 541614, 541618, 541690
56	Solid Waste Combustors and Incinerators	562213
All except 31-33	All others	Remainder of codes not specified above, drawn separately from each 2-digit NAICS (15 establishments each)

TABLE A4.3. NAICS definition of sample segments

Headquarters establishments: Those establishments in the Dunn and Bradstreet (D&B) database with "Status Code" = 1 (indicating headquarters), allocated according to 2-digit NAICS code groups:

	2-Digit NAICS
Manufacturing HQs	31-33
Industry HQs	21, 22, 23
Trade HQs	42, 44, 45, 52, 53, 55, 61, 62, 71, 72, 81
Professional HQs	48, 49, 51, 54, 56

Main Sample: Establishments in the D&B database not identified as headquarters. Some were drawn from every non-farm, non-government NAICS code; specific sets of 6-digit codes were sample at higher rates as defined in table A4.3.

A4.3.2. Sample Distribution

Segment	Sampled	Do not exist	Responses	Phone survey	Energy-related innovation	Answered follow-up
Seed	32		8		7	4
NEF	50	20	4		3	2
Manf. HQs	75	3	12	5	3	2
Industry HQs	50	8	4	3	1	1
Trade HQs	50	3	7	3	1	
Prof HQs	50	2	6	3	2	1
Enr. Mining	50	5	5	2	3	
Enr. Utilities	135	19	19	7	10	4
Enr. Constr	50	9	8	5		
Enr. Pipe	30	3	4	1		
Enr. Equip	220	26	31	11	13	4
High Use	100	9	16	9	4	1
Other Manf	40	6	4	2	1	
R&D	150	22	14	10	8	4
Eng & Envir	75	18	9	3	2	2
Other Innov	75	15	12	3	6	4
Incinerators	15	4	1	2	1	
All others	255	25	28	13	2	
Total	1502	197	192	82	67	29

TABLE A4.4. Sample distribution and outcomes

References

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Chapter 5 Appendix

Chapter five is based on an extensive quantitative analysis of international cooperation activities on energy technology innovation. This appendix provides the results of these analyses and an interpretation of the results. The appendix is subdivided into three sections. The first section provides a detailed analysis of the global landscape of international ERD3 cooperation activities. The second section provides a detailed analysis of the large number of quantitative databases that have been used to inform this study. The third section provides a more in depth discussion of the scientific concepts and theories that have been used to inform the proposed organizational structure for coordinating and managing international cooperation projects within the U.S. government.

A5.1. Overview of Existing International ERD3 Cooperation Activities

Between the 1950s and 1973, bilateral agreements were the main channel through which the U.S. government pursued international cooperation on energy technology innovation (ETI). This changed after the 1973 oil crisis, when the U.S. government was actively involved in founding the International Energy Agency. Nowadays, there are at least 22 channels through which the U.S. government engages in international cooperation on energy technology innovation. This section provides an overview of the international cooperation activities on ETI that take place through different platforms and sketches a rough landscape of the types of technologies that are covered. The section subdivides these platforms into three different categories: (1) bilateral agreements; (2) broad and inclusive multilateral agreements; (3) country-specific multilateral agreements; (4) interest-specific multilateral agreements; and (5) multilateral development banks.

A.5.1.1. Bilateral Agreements

Bilateral agreements are still a major platform for international cooperation. In May 2010, DOE's Program Office of International Science & Technology Cooperation had listed 218 energy-related bilateral agreements with 74 different countries (excluding any bilateral agreements with international organizations). Of these 218 bilateral agreements, 36 agreements focused on illicit trafficking of nuclear materials and 175 agreements with 46 countries focused on energy technology cooperation. Of these 175 agreements, 43% were focused on nuclear energy, 10% on renewables, 8% on energy efficiency, and 7% on fossil energy. China was the largest recipient of bilateral agreements with 29 agreements, followed by France (15), Japan (11), Russia (11), Canada, India, and South Africa (each seven agreements).[4]

4 These totals are not the same as the totals in Figure A5.1, because some agreements address multiple energy technology categories.

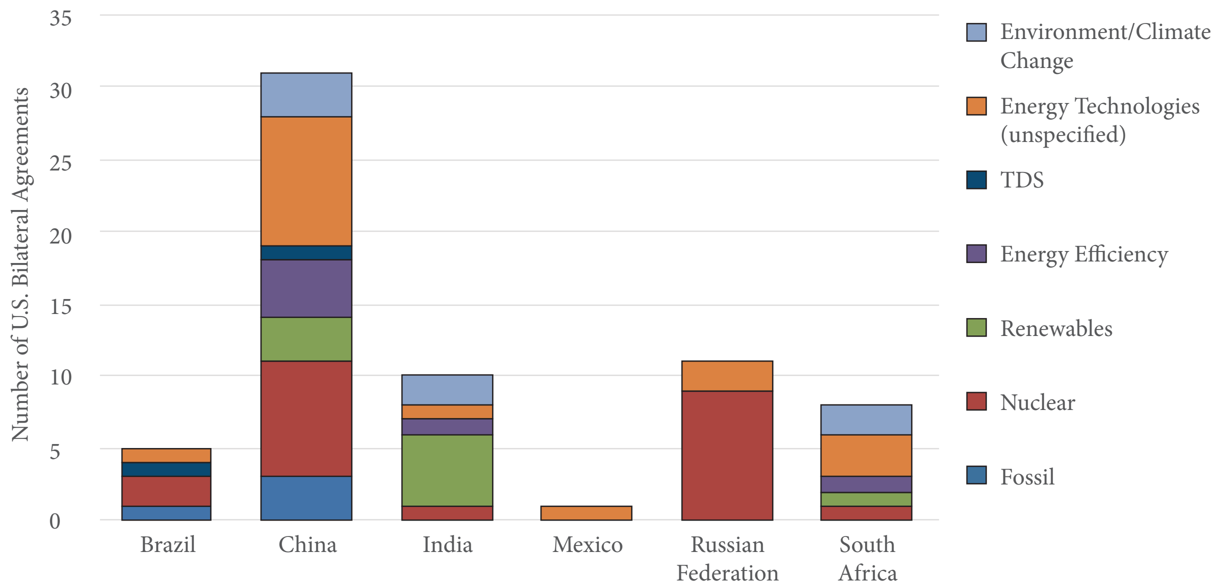

FIGURE A5.1. U.S. bilateral agreements with Brazil, China, India, Mexico, Russia, and South Africa.

It is important to emphasize that a very large percentage of these bilateral agreements are inactive. They can be used in case international activities need to be supported by a formal agreement, but there is no requirement for actual activities in each of these bilateral agreements. Furthermore, not all bilateral agreements are the same. Legally binding science and technology cooperation agreements need to be approved by State (State 2001), while other agreements are non-binding. Furthermore, some bilateral agreements are part of larger initiatives on international cooperation. For example, DOE initiated the Nuclear Energy Initiative (NERI) in 1999 to support international cooperation on nuclear energy. In 2010, this initiative (now called I-NERI) is supported by bilateral agreements with Brazil, Canada, the EU, France (3 agreements), Japan (2), Korea (2), and OECD-NEA (DOE 2009).

A5.1.2. Broad and inclusive multilateral agreements

Besides bilateral agreements, the U.S. government is involved in several multilateral agreements. Here, we make a distinction between multilateral agreements that are broad and inclusive, interest-specific, country-specific, or region specific. At the moment, the U.S. has broad multilateral agreements through several UN-led initiatives. The UNFCCC Clean Development Mechanism (CDM) is a mechanism that allows countries and firms to do reduce greenhouse gas emissions in other countries than their own by financing projects. Dechezleprêtre, Glachant et al. (2008) found that within a sample of 664 CDM projects 43% involved either equipment or knowledge transfer or both, while Seres and Haites (2008) found that 36% of all 3296 registered and proposed CDM projects claim technology transfer. Both studies find that most technology transfer goes to countries like Brazil, China, India, and Mexico (73% according to

Decehzleprêtre, Glachant et al. (2008)). Furthermore, both studies claim that around 70% of all transfer of knowledge and equipment comes from countries like Japan, Germany, the United States, and France and that 19% of the suppliers were located in the U.S. (Dechezleprêtre, Glachant et al. 2008; Seres and Haites 2008).

The Bali Action Plan is a more recent agreement within UNFCCC to launch a comprehensive effort to address climate change issues through long-term cooperative action. One of the action items in the Bali Action Plan consists of enhancing technology development and transfer to support both mitigation and adaptation activities through (1) the removal of barriers to the development and transfer of technologies to developing countries; (2) the acceleration of deployment, diffusion, and transfer of environmentally sound technologies, (3) the cooperation on R&D; and (4) the support of sector-to-sector technology cooperation (UNFCCC 2008). An Expert Group on Technology Transfer (EGTT), which developed a long-term strategy for diffusion and transfer of technologies beyond 2012 (EGTT 2009), was terminated at the COP16 meeting at Cancun. Instead, a Technology Executive Committee (TEC) was established to advise on technology needs, technology development and transfer, and a Climate Technology Centre was established to enhance technical cooperation, international partnerships, and technical assistance through a Network of national, regional, sectoral and international technology networks, organizations and initiatives (UNFCCC 2010).

There are several other UN-activities that address international cooperation on energy technology innovation. In 2001, the UN had four different programs and eight different agencies involved in international energy activities (United Nations 2001) and, in 2009, the number of international energy partnerships under the UN Commission on Sustainable Development alone had increased to 46. However, Szulecki, Pattberg et al. (2010) found that 21 of these partnerships are inactive and only eight partnerships are actually developing new energy infrastructure

A5.1.3. Country-specific agreements

Country-specific agreements are another form of multilateral cooperation agreements. The U.S. government has a most longstanding involvement in the IEA's Implementing Agreements. Country membership of the IEA, however, is restricted to the largest energy consuming OECD countries and therefore does not include any of the BRIMCS countries. However, the IEA allows non-members to participate in Implementing Agreements. In 2010, the U.S. government participated in 40 of the 42 Implementing Agreements, which is higher than any other IEA or IEA non-member country. The only two agreements that the U.S. government did not sign up to are "fluidized bed conversion" and "renewable energy technology deployment (RETD)" (IEA 2010). Despite the participation of a large number of countries (42) in IEA Implementing Agreements, this agreement has, almost since its reception, received considerable critique for a lack of "common strategy" and a lack of projects besides information sharing and knowledge exchange (Bobrow and Kudrle 1979).

The Asia Pacific Agreement on Energy and Climate (APP)[5] is another multilateral agreement formed in July 2005 with a specific member base of only seven countries: Australia, Canada,[6] China, India, Japan, Korea, and the United States. It came "unofficially" to an end at the second Clean Energy Ministerial (CEM) meeting in April 2011, when CEM was announced as a "follow up" of the APP. The APP is a technology-focused public-private arrangement, which is organized in sectoral-based "task forces" and focuses on the transfer of clean technologies, facilitating greenhouse gas reducing practices, and R&D (Betsill 2010). The U.S. government, together with Australia, had a pivotal role in establishing APP, because both countries did not sign the Kyoto Protocol and both wanted to focus the discussion on technology rather than emissions reduction targets (Taplin and McGee 2010). Over 170 projects have been initiated, involving $200 million, but only seven projects have been completed so far and new funding is required to complete any of the flagship projects.

Closer to home, the U.S. government is involved in several region-specific multilateral cooperative agreements on energy and climate change. Since 1993, the Inter-American Institute for Global Change Research (IAI)[7] specifically focuses on S&T collaboration and scientific capacity building in its member countries, while the Energy and Climate Partnership of the Americas (ECPA)[8] formed in 2009, focuses more on trade, infrastructure development, energy access, information exchange, and (since its last ministerial in April 2010) sustainable forestry and land use.

A more recent country-specific agreement is the Major Economies Forum on Energy and Climate (MEF), launched in March 2009, which includes the 17 largest economies of the world.[9] MEF is seen by the U.S. government as a "political" platform, and its objective is to facilitate and implement concrete action plans to provide clean energy and to reduce greenhouse gas emissions. Although it is intended to facilitate the UNFCCC negotiations, the MEF also appeals to those proponents who believe that agreements involving a small number of countries are easier to implement than any cooperative agreements within the UNFCCC. After an initial effort to identify potential actions through 10 technology action

5 www.asiapacificpartnership.org, accessed December 2010.
6 Canada joined in 2007.
7 The IAI includes Argentina, Bolivia, Brazil, Canada, Chile, Colombia, Costa Rica, Cuba Dominican Republic, Ecuador, Guatemala, Jamaica, Mexico, Panama, Paraguay, Peru, Uruguay, United States, and Venezuela.
8 The ECPA includes Antigua and Barbuda, Bahamas, Brazil, Canada, Chile, Colombia, Costa Rica, Dominican Republic, Granada, Mexico, Peru, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, United States, and Venezuela. The website is www.iai.net, accessed December 2010.
9 The MEF includes Australia, Brazil, Canada, China, European Union, France, Germany, India, Indonesia, Italy, Japan, Korea, Mexico, Russia, South Africa, United Kingdom, and United States. The website is www.majoreconomiesforum.org, accessed December 2010.

plans, the first Clean Energy Ministerial (CEM) in July 2010 resulted in 11 global initiatives on energy efficiency, clean energy, and energy access. Although there are high hopes for "concrete action plans" being developed, MEF-CEM is still in its infancy. The second CEM meeting in April 2011, however, did show that substantial progress was made in embedding some of the CEM initiatives in existing platforms. For example, the initiative on energy-efficient appliances has become part of the International Partnership on Energy Efficiency Cooperation (IPEEC) and the initiatives on "smart grid" and "electric vehicles" are currently organized as Implementing Agreements within the International Energy Agency.

A5.1.4. Interest-specific multilateral agreements

Interest-specific multilateral agreements focus on a particular technology area. Some of these agreements are administrated under the UNFCCC allowing for a wide range of participants, while others are much more specific. For example, the U.S. government is involved in several other initiatives that have been launched to include a larger representation of countries worldwide in new renewable energy technologies initiatives, such as the International Renewable Energy Agency (IRENA),[10] the Renewable Energy Network of the 21st Century (REN21),[11] and the Global Bioenergy Partnership (GBEP)[12] (IRENA 2008; Lesage, Van de Graaf et al. 2010). In particular, the relative ease with which IRENA was established outside of the realms of the UN shows the eagerness of countries to collaborate on renewable energy technology issues.

Other interest-specific agreements are much more focused on a small number of countries. The U.S. government has initiated and signed up to several of these kinds of agreements (DOE 2005; State 2010). The Carbon Sequestration Leadership Forum (CSLF),[13] established in 2003, consists of 24 countries promoting collaborative RD&D on cost-effective technologies to separate and capture CO2 through meetings, workshops, and by "recognizing" demonstration projects in its member countries. The International Partnership for a Hydrogen Economy (IPHE),[14] also established in 2003, consists of 17 countries and provides a mechanism for international RD&D and commercialization activities related to hydrogen and fuel cell technology. IPHE organizes meetings, workshops, conferences and established 31 collaborative projects between 2005 and 2008 (IPHE 2009). However, only one new project was started in 2008 and no new projects were initiated in 2009. On energy efficiency, the U.S. government has multilateral agreements through the EPA involvement in both the Collaborative Labeling and Ap-

10 www.irena.org, accessed December 2010.
11 www.ren21.net, accessed December 2010.
12 www.globalbioenergy.org, accessed December 2010.
13 www.cslforum.org, accessed December 2010.
14 www.iphe.net, accessed December 2010.

pliance Standards Program (CLASP)[15] and the International Environmental Strategies plan (IES). The latter program assists, since 1998 and with support from USAID and NREL, in measuring the environmental impacts of local energy solutions in eight countries.[16] In 2009, the United States signed an agreement to establish an International Partnership for Energy Efficiency Cooperation (IPEEC).[17] The IPEEC secretariat will be based within the IEA, but it will be an independent organization facilitating information exchange on best practices and collaborative projects to increase energy efficiency (IPEEC 2009). Finally, the U.S. government, together with the government of Mexico, has announced the launch of the Global Methane Initiative (GMI)[18] in October 2010. The GMI is an extension of the Methane to Markets (M2M) Partnership, which was established by 14 countries in 2004 to cooperate on accelerating methane emission reducing technologies. The M2M grew to include 38 member countries in 2010 and supports local methane reducing projects through technical and financial support. The GMI will extend existing activities by including other sectors that emit methane, action plans for member countries, and additional resource commitment (GMI 2010). Finally, State launched the Global Shale Gas Initiative (GSGI) in April 2010 in order to "help countries seeking to utilize their unconventional natural gas resources to identify and develop them safely and economically." Since the initial launch, five bilateral agreements have been signed with China, India, Jordan, Poland, and Ukraine, and a total of 20 countries were invited to a follow-up conference in August 2010. [19]

Besides bilateral agreements on nuclear energy, the U.S. government is also involved in multilateral agreements. The longest running collaborative agreement is the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) at the International Atomic Energy Agency (IAEA).[20] INRPO was established in 2000 and includes 30 Member States. INPRO currently support 11 collaborative projects spread out over four main programs (energy system assessments, global scenarios, nuclear technology innovation, and institutional arrangements) and two cross-cutting programs. The Generation IV International Forum (GIF or Gen IV) was signed in 2001 by its nine founding members[21] and, since April 2010, 10 of the 13 members have signed the framework agreement (Argentina, Brazil, and the UK are non-active members). GIF currently supports 9 different collaborative projects on four different nuclear energy technologies.

15 www.clasponline.org, accessed December 2010.

16 The countries are Argentina, Brazil, Chile, China, India, Mexico, Philippines, and Korea. The website is www.epa.gov/ies, accessed December 2010.

17 www.ipeec.org, accessed December 2010.

18 www.globalmethane.org, accessed December 2010.

19 Personal communication with M. Sullivan at the Office of the Coordinator for International Energy Affairs, U.S. Department of State, 20 April 2011.

20 www.iaea.org/INPRO, accessed December 2010.

21 The Founding Members of GIF include Argentina, Brazil, Canada, France, Japan, Korea, South Africa, the United Kingdom, and the United States. Switzerland joined in 2002, Euratom in 2003, and China and Russia in 2006. The website is www.gen-4.org, accessed December 2010.

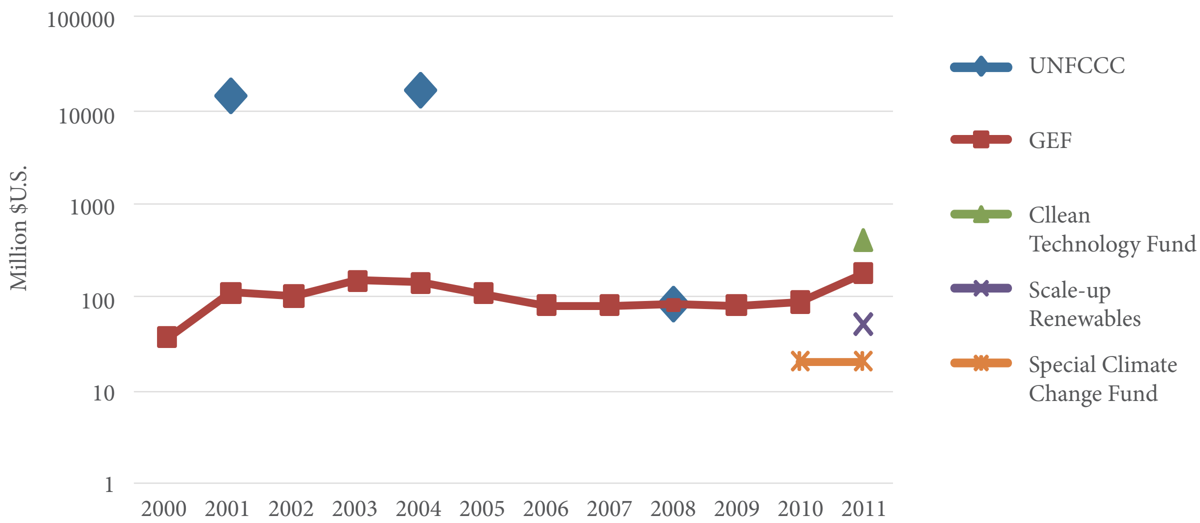

FIGURE A5.2. U.S. government (logarithmic scale) contributions to the UNFCCC, GEF, Clean Technology Fund, Scale-Up Renewables, and Special Climate Change Fund between 2000 and 2011.

A5.1.5. Other international agreements

Besides formal cooperation agreements, the U.S. government is also involved in international cooperation activities through a host of other forms of memoranda of agreements (MOUs) or dialogues. These partnerships often group several already existing activities into a common framework, which makes it difficult to determine whether new initiatives consists of existing projects organized differently or whether they are actually constituted of new projects. For example, the U.S. government has a partnership with India to advance clean energy called PACE[22] (Office of the Press Secretary 2010). PACE is developed by State, but its R&D component is led by DOE and its deployment component is led by USAID. Furthermore, it contains separate MOUs between U.S. Trade and Development Agency (USTDA), the Department of Commerce (DOC), and Indian partners on trade (USTDA 2010) and additional funding by the Overseas Private Investment Corporation (OPIC) to the Global Environment Facility (GEF) to finance investments in clean energy by U.S. companies in India.

Finally, the U.S. government is also involved in several international platforms that indirectly affect global energy technology innovation. The Treasury financially supports some ongoing and new international programs that promote the adoption of clean energy technologies. The GEF (see previous paragraph) is a program that started in 1991 and which supports energy efficiency, renewable energy, transport, and low GHG-emitting energy technologies (GEF 2008). All of the BRIMCS countries have received funding from the GEF for one or more of these projects. New initiatives funded by the Treasury

22 U.S.-Indo Partnership to Advance Clean Energy

are the Clean Technology Fund (CIF 2010b) and the program on scaling-up renewable energy (SREP) within the Strategic Climate Fund (CIF 2010a). Finally, State provides financial supports the UNFCCC for energy projects to mitigate GHG-emissions. U.S. government funding to each of these three programs can be found in Figure A5.2.

Figure A5.2 shows an overview of U.S. government engagement with the BRIMCS countries through their multilateral agreements. The graph shows that, from a U.S. perspective, there is no consistent pattern or strategy that can be detected.

A5.2. Quantitative Analysis

This section describes the quantitative databases that have been used to analyze international cooperation activities as well as the results of these analyses. Three databases have been specifically constructed for the purpose of this study and include a longitudinal study of scientific publications on energy technology innovation between 1973 and 2009, a longitudinal study of international interfirm R&D partnerships between 1963 and 2006, and an analysis of the Annexes within the IEA Implementing Agreements between 1975 and 2010. The construction of these databases, their limitations, and the results will be discussed in the first three subsections. The next three subsections discuss our analysis based on existing databases of bilateral agreements, overseas development aid, and import and export flows of energy technologies. The final subsection discusses the results of an actor analysis of stakeholder involvement in national and international activities on carbon capture and sequestration technologies.

A5.2.1. Scientific collaborations database

The methodology consists of a quantitative analysis of scientific papers on renewable energy, nuclear energy, and fossil energy technology between 1973 and 2009. The authors' institutions have been used to analyze international cooperation between different countries. The method consists of three steps. First, a number of journals have been selected as the basis for the analysis for each of the three technology categories. The selection of journals was based on the journals' description of aim and scope, their Thomson Reuters impact factors[23] and SCImago Journal Rankings,[24] two different ranking methods for scientific journals. The rankings were from the years 2008 and 2009, respectively. The final selection only included international journals, it included the highest ranked journals, and information about whether the journal was specific to any of the three energy technology categories.[25] Subsequently, the

23 http://thomsonreuters.com/products_services/science/free/essays/impact_factor/
24 http://www.scimagojr.com/journalrank.php
25 For example, the journal "Energy Policy" was not included in any of the selections, because its papers address all energy technologies.

Category	Journal	Impact Factor	Year of Foundation
Fossil Energy	Energy & Fuels	8.84	1987
	Progress in Energy and Combustion Science	8	1975
	Fuel	2.536	1970
	Combustion and Flame	2.16	1957
	Fuel Processing Technology	2.066	1977
	Proceedings of the Combustion Institute	1.906	2000
	International Journal of Coal Geology	1.768	1980
Renewable Energy	Bioresource Technology	4.453	1991
	Renewable and Sustainable Energy Reviews	4.075	1997
	Biofuels, Bioproducts and Biorefining	2.909	2007
	Solar Energy Materials and Solar Cells	2.788	1992
	Progress in Photovoltaics: Research and Applications	2.652	1993
	Biomass and Bioenergy	2.54	1991
	Renewable Energy, An International Journal	1.663	1991
	Solar Energy	1.607	1957
	Wind Energy	1.271	1998
	Environmental Progress & Sustainable Energy	1.054	1982
Nuclear Energy	Journal of High Energy Physics	5.375	1997
	Plasma Physics and Controlled Fusion	2.299	1960
	Nuclear Fusion	2.73	1992
	IEEE Transactions on Nuclear Science	1.11	1963
	Nuclear Engineering and Design	0.874	1965
	Nuclear Science and Engineering	0.87	1956
	Annals of Nuclear Energy	0.831	1975
	Fusion Engineering and Design	0.828	1985

TABLE A5.1. Selection of scientific energy journals used as the basis for the analysis.

selections were sent to one U.S. technology specialist and one international technology specialist for each of the three technology categories with the question whether the selection of journals were a representation for their field. Based on their suggestions, we either included or deleted journals. The total number of journals ranged between seven and 10 journals, which resulted in a representative sample of 2277 papers for fossil energy, 3396 papers on nuclear energy, and 3216 papers for renewable energy in 2009. The selection of journals is presented in Table A5.1.

Second, the database Scopus[26] was used to find the authors' institutions for all papers published in these journals between 1973 and 2009. The year 1973 was chosen as starting point because it was after the first oil shock that renewable energy technologies received more prominent attention as a possible solution for energy security in the United States and elsewhere. For each journal article, the location of the authors' institutions have been used as a indication for international cooperation between countries. The following data has been analyzed:

1) Whether the paper was published by an individual institution from one single country;

2) Whether the paper was published through collaboration between multiple institutions from the same country;

3) Whether the paper was published through collaboration between multiple institutions from different countries.

Third, on the basis of this information the following indicators have been developed for each country:

1. The number of papers published by a country's institution per year.

2. The number of institutions that have contributed to one or more papers per year per country.

3. The percentage of papers written by individual institutions per year per country.

4. The percentage of papers written by nationally collaborating institutions per year per country.

Authors	Year	Source title	Volume	Issue	Affiliations
Fujii I., Tsuchiya K., Higano M., Yamada J.	1985	Solar Energy	34	05-Apr	Department of Mechanical Engineering, Meiji University at Kawasaki, Japan
Tanaka K., Murata S., Harada K.	1985	Solar Energy	34	05-Apr	National Chemical Laboratory for Industry, Japan
Kimura H., Kai J.	1985	Solar Energy	35	6	Central Research Laboratory, Mitsubishi Electric Corporation, Japan
Saitoh T., Matsuhashi H., Ono T.	1985	Solar Energy	35	6	Department of Mechanical Engineering II, Tohoku University, Japan; Mitsubishi Heavy Industries Co. Ltd., Japan; Toshiba Corporation, Japan
Rao C.R.N., Takashima T.	1985	Solar Energy	34	05-Apr	Department of Atmospheric Sciences, Oregon State University, United States; Meteorological Research Institute, Japan

TABLE A5.2. Extract from the database of scientific publications on renewable energy technologies displaying Japan's publications in 1985.

26 http://info.scopus.com/

5. The percentage of papers written by internationally collaborating institutions per year per country.

6. The percentage of collaborations with national institutions per year per country.

7. The percentage of collaborations with international institutions per year per country.

8. The number of collaborations with every country per year per country.

Table A5.2 provides an example of how the previously mentioned indicators have been measured. The table presents the scientific papers on renewable energy technology written by authors from Japanese institutions in 1985 within the database.

The database shows that seven Japanese institutions have published scientific papers (if the same institution publishes two different papers, both contributions are counted). There are five publications in which Japanese institutions have been involved, from which only one publication was with a foreign institution. The first three publications have been published by individual institutions and the last two papers are collaborations. Three national collaborations took place: (1) Tohoku University with Mitsubishi; (2) Tohoku University with Toshiba; and (3) Mitsubishi with Toshiba. On the basis of this data, Table A5.3 presents the indicators that have been collected for Japan in 1985.

The same indicators have been collected for each of the years between 1973 and 2009 for 214 other countries and/or independent states.[27]

Indicators	Japan (1985)
No. Institutions	7
No. Publications	5
% individual papers	0.60
% national papers	0.20
% international papers	0.20
% collaborations nationally	0.75
% collaborations internationally	0.25
No. Collaborations nationally	3
No. Collaborations with United States	1

TABLE A5.3. Indicators for Japan's renewable energy technology publications in 1985.

27 Some countries have changed names between 1973 and 2009, which is why we have 214 different countries in our database.

Limitations

One should take into consideration that this database has not been developed to provide a representative overview of all scientific developments in energy technologies, but to provide a representative overview of international collaborations in the context of energy technologies. To test whether this set of journals provides a representative sample of international collaboration activities, we attempted to analyze all publications on renewable energy technology in 2009.[28] The results show a total of 717 publications with a distribution of 51% single institution papers, 31% papers through national collaborations, and 18% papers by international collaborations. Our dataset of scientific papers on renewable energy technology, based on the 10 journals above, contains 312 articles with 45% single institution papers, 37% national collaborations, and 17% international collaborations for the same year.

However, there are several limitations which have to be considered when interpreting and analyzing these results.

1. The analysis is based on a representative selection of scientific journals. There are many other journals, both nationally and internationally, which exist or have existed in which scientific research has been published.

2. Published research only presents a fraction of all international research collaborations that take place.

3. The journals have been selected on the basis of their rankings in 2008 and 2009. These rankings change every year, which means that some of the journals might have had lower rankings in previous years and/or did not exist over the whole period between 1973 and 2009.

4. Because of scientists' mobility, the authors' institutions presented in the database might not be the same as the institutions in which the research took place.

5. If more than two institutions collaborate, not every institution has to collaborate with each other. There might be a centrally located institution which collaborates with two or more other institutions, which do not have any contact among each other.

6. No articles have been excluded from the database, except for errata and papers from which the authors' institution was not provided. This means that the database includes not only research articles, but also opinion articles, overview papers, and/or papers that do not directly describe

28 We used the following search term in scopus: "renewable energy" OR "solar energy" OR "wind energy" OR "solar thermal" OR "photovoltaics" OR "solar cells" OR "solar electricity" OR "bioenergy" OR "biomass energy" OR "biofuel" OR "geothermal energy" OR "wave energy" OR "ocean energy" OR "hydro energy."

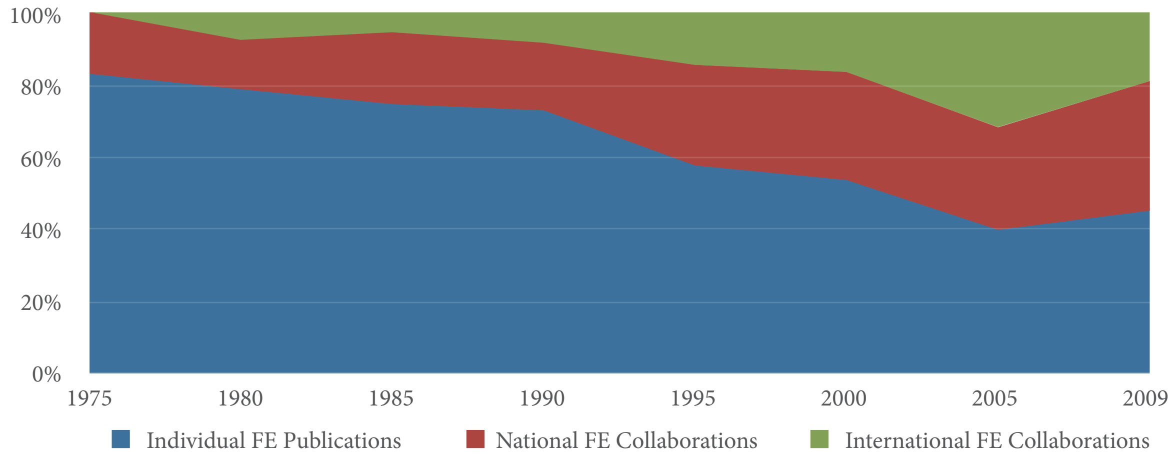

FIGURE A5.3. Percentage of individual, national and international collaborations on fossil energy (FE) papers.

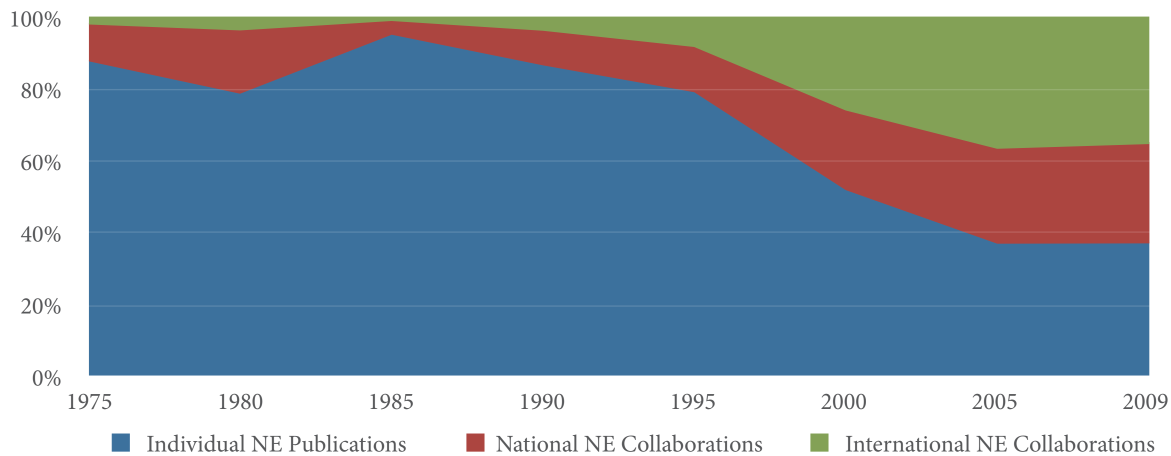

FIGURE A5.4. Percentage of individual, national and international collaborations on nuclear energy (NE) papers

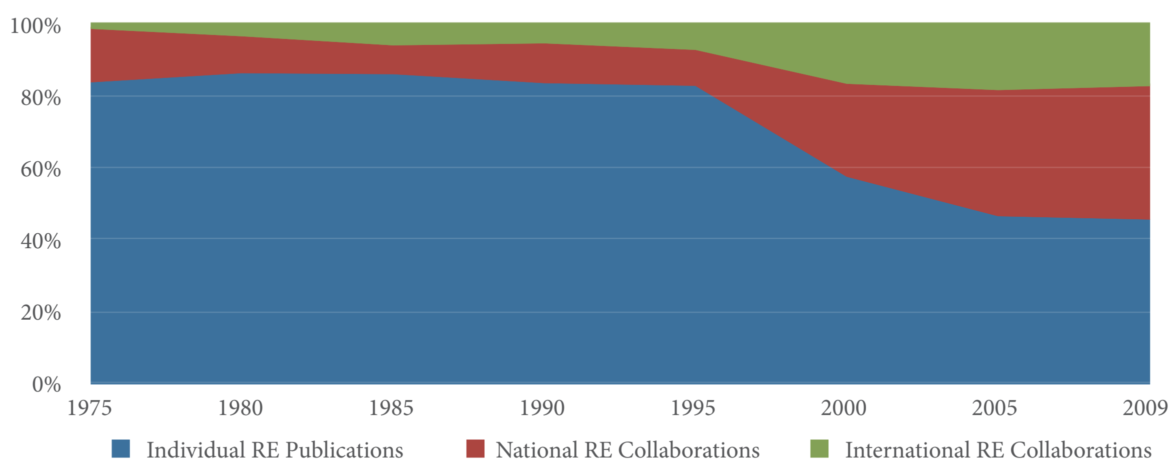

FIGURE A5.5. Percentage of individual, national and international collaborations on renewable energy (RE) papers.

R&D in energy technologies.[29]

7. No distinction has been made between universities, companies, national labs and/or governmental departments.

8. Breakthrough research could have been in other journals (e.g., fundamental breakthroughs in energy technology R&D might be reported in journals like Nature or Science).

Results

International science collaborations are mostly studied through international co-authorship of papers (Frame and Carpenter 1979; Wagner and Leydesdorff 2005b). A study by Wagner and Leydesdorff (2005a) has shown that, based on the average percentage of internationally co-authored documents as recorded in the Science Citation Index (SCI), international collaborations rose from 8.7% in 1990 to 15.6% in 2000. Our data on scientific papers in several energy journals in the areas of renewable energy, fossil energy, and nuclear energy shows that, similar to the general trend, international cooperation has increased significantly between 1990 and 2005 (see Figures A5.3-A5.5). Since then, the growth in international cooperation has leveled off to 17% for renewable energy, 19% in fossil energy (although 2005 was an exceptional year with 32% international cooperation), and 35% in nuclear energy. Although the results of this analysis are not directly comparable with the data on general scientific collaborations (because of the different methods used), this data suggests that the international scientific collaborations on energy technologies are at least comparable with other areas of research.

Our database on U.S. science collaborations in the areas of nuclear, fossil, and renewable energy shows that U.S. institutions collaborate with a very large number of different countries. In 2009, the database containsed papers by U.S. institutions collaborating with 44 different countries on renewable energy papers, 49 different countries on nuclear energy papers, and 45 countries on fossil energy papers. If we look at specific countries, we can see that the growth in international cooperation is not uniform for each country. Our main report (see Figure 5.2.) already showed the important changes that have taken place within the scientific publications on renewable energy technology, where countries like China and India have grown in terms of number of contributions[30] and number of international collaborations. Figure A5.6 and Figure A5.7 show the results for our nuclear energy database and our fossil energy database between 2000 and 2009, respectively.

29 The reason to include all articles is the following; if the reviewers and editors of these journals have included these articles, then it is assumed they must have been relevant for advances in renewable energy technologies.

30 The X-as represents the number of contributions rather than the number of publications. A paper that has multiple national institutions is counted on the basis of the number of institutions involved in that particular paper instead of counting the number of papers with an institution from a particular country.

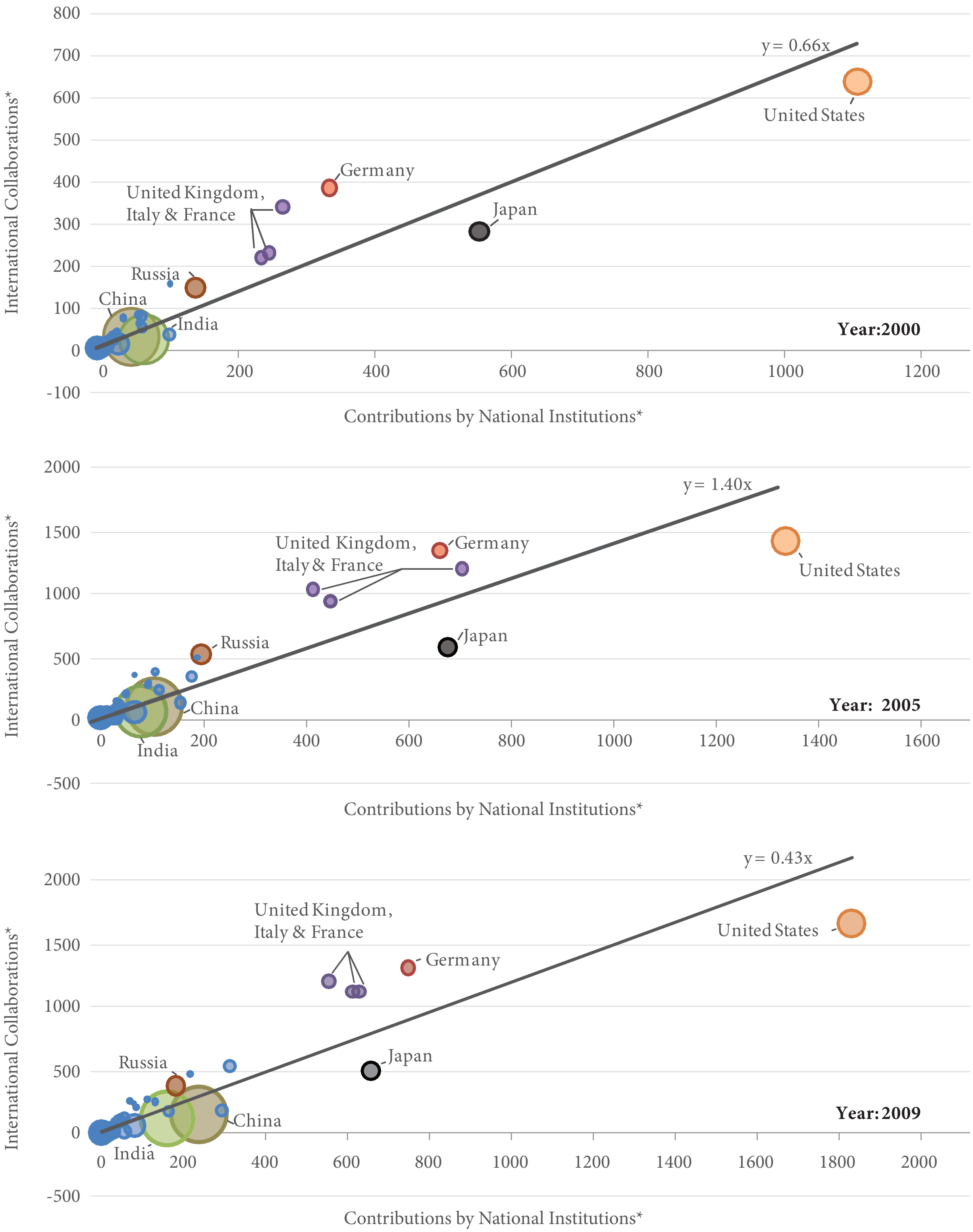

FIGURE A5.6. International scientific collaborations on nuclear energy technologies between 2000 and 2009. The size of the bubble represents the population of the country. The horizontal axis represents the number of publications in the 6 top-ranked renewable energy journals with at least an author from an institution in a particular country; the vertical axis represents the number of publications in these journals by institutions from a particular country and at least one author from an institution in a different country.

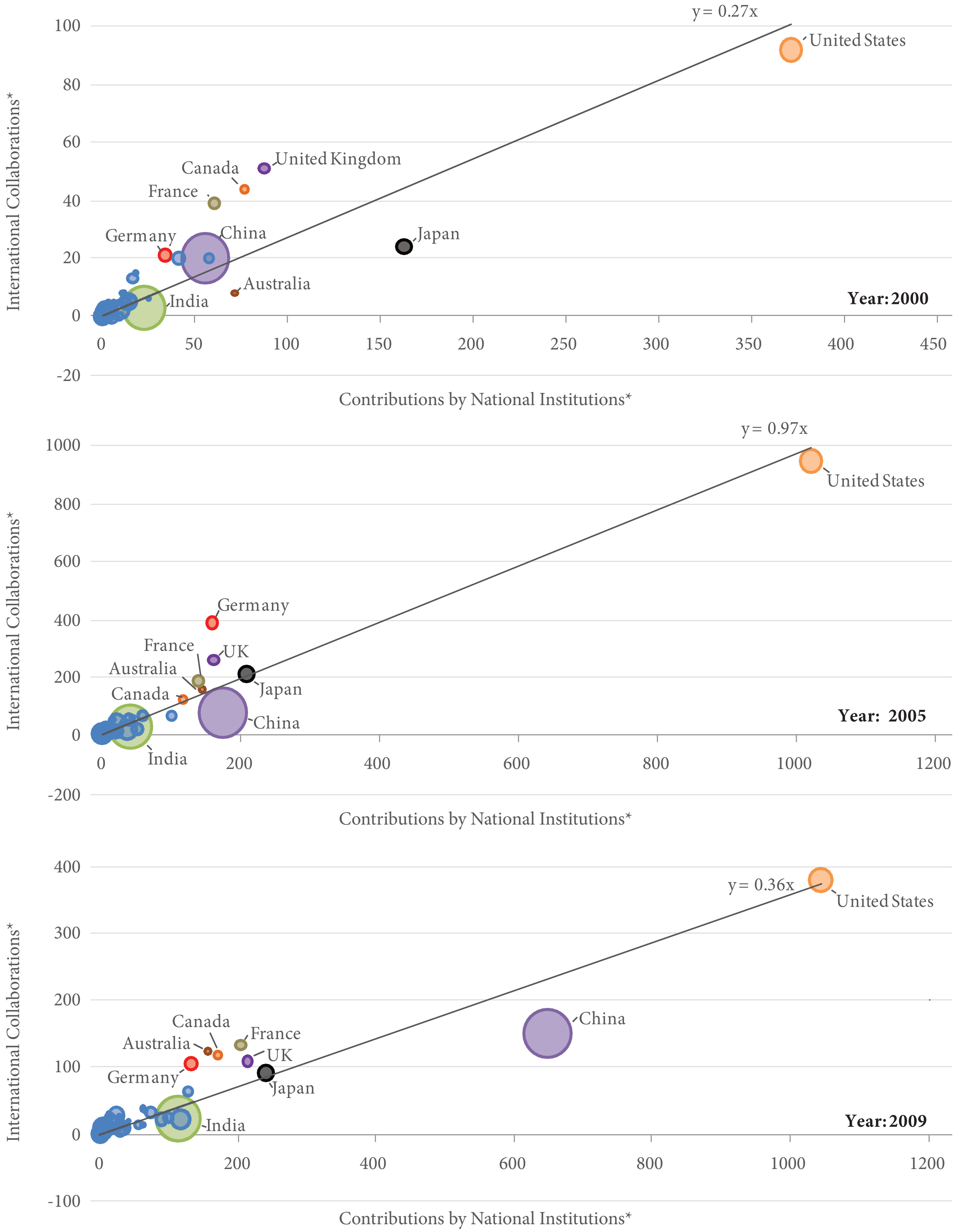

FIGURE A5.7. International scientific collaborations on fossil energy technologies between 2000 and 2009. The size of the bubble represents the population of the country. The horizontal axis represents the number of publications in the 6 top-ranked renewable energy journals with at least an author from an institution in a particular country; the vertical axis represents the number of publications in these journals by institutions from a particular country and at least one author from an institution in a different country.

Figures A5.6 and A5.7 show the evolution of international collaborations in scientific publications published in a limited set of journals for several countries around the world. In scientific collaborations on nuclear energy, the countries that are involved in international collaborations are most stable. The United States, Germany, and Japan are involved in international cooperation the most, followed by a cluster of the United Kingdom, Italy, and France. More interestingly, between 2000 and 2009 China has overtaken India in terms of publications and international collaborations on nuclear energy technology.

In fossil energy, there have also been dramatic changes in the last 10 years. The United States still dominates the number of contributions and the number of international cooperations, but Japan's position is now equal to a range of other developed countries (France, UK, Canada, Australia, and Germany). Between 2005 and 2009, China has progressed substantially. Although its number of international cooperations compared to its contributions is still relatively lower than the group of developed countries mentioned previously, its number of contributions has more than tripled in the last five years.

We can also use this data to examine with whom countries are collaborating. Figure A5.8 shows that the United States, China, and India are collaborating most with Canada, Korea, Taiwan, Japan, the United Kingdom, Germany, and Sweden. Furthermore, there seems to be some regional clustering with China collaborating more with Asia-Pacific countries (Hong Kong, Japan, Australia) than with European or Latin American countries.

All in all, this data shows that the number of international scientific collaborations and the diversity of collaborators has increased dramatically in the last 10 years (roughly threefold). This means that there are much more options for collaborating than there were 10 years ago. This is also evident if we analyze the extent to which U.S. research institutions are preferred partners for international scientific

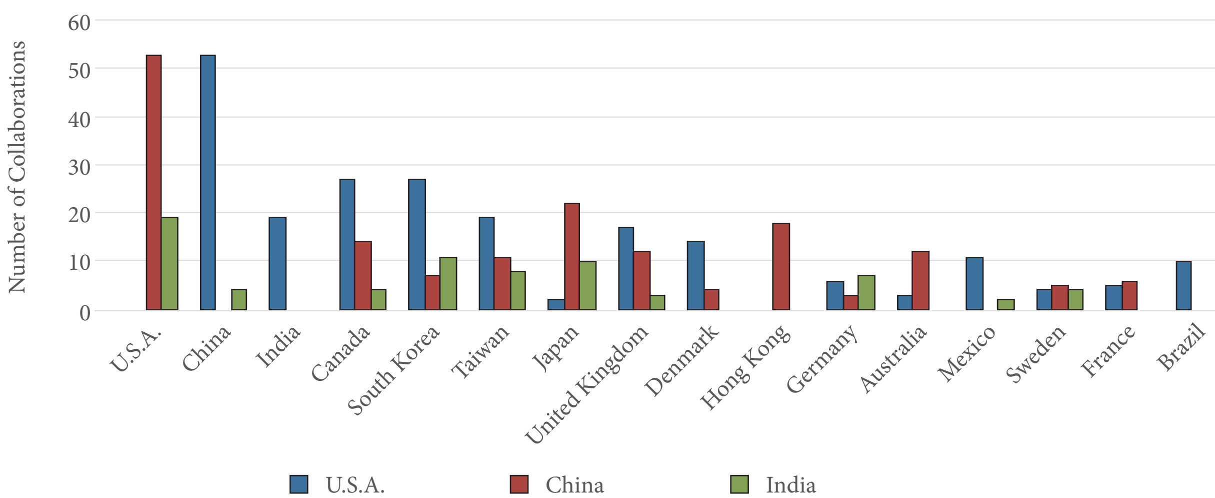

FIGURE A5.8. Number of collaborations of the United States, China, and India on renewable energy technology papers in 2009.

(nuclear energy)	2000	2005	2009
Japan	31%	31%	28%
Germany	17%	11%	15%
Italy	17%	14%	15%
United Kingdom	32%	18%	20%
France	26%	13%	16%
Russian Federation	25%	17%	10%
Switzerland	24%	13%	15%
Spain	37%	10%	8%
Netherlands	18%	9%	16%
Finland	8%	6%	7%
Belgium	26%	3%	7%
Canada	46%	45%	25%
South Korea	64%	31%	38%
China	21%	27%	35%
India	45%	27%	17%

TABLE A5.4. Percentage of international science collaborations on nuclear energy of non-U.S.–based institutions with U.S.-based institutions on the 8 top-ranked nuclear energy technology journals.

(renewable energy)	2000	2005	2009
Germany	14%	9%	5%
China	36%	3%	27%
France	3%	0%	4%
United Kingdom	0%	0%	14%
Netherlands	2%	13%	2%
Spain	0%	0%	6%
India	10%	19%	18%
Sweden	3%	17%	5%
Japan	0%	11%	3%
Canada	40%	13%	26%
Australia	0%	0%	4%
South Korea		43%	43%
Italy	0%	0%	11%
Denmark	25%	8%	24%

TABLE A5.5. Percentage of international science collaborations on renewable energy of non-U.S.–based institutions with U.S.-based institutions on the 10 top-ranked renewable energy technology journals.

collaboration. Table 5.4 shows the fraction of international collaborations on nuclear energy technology publications with U.S.-based institutions between 2000 and 2009 for the 15 countries with the highest number of international collaborations on nuclear energy papers in eight journals. Except for China, nuclear energy collaborations with the United States have percentage-wise declined or remained steady between 2000 and 2009.

(fossil energy)	2000	2004	2005	2009
Germany	43%	12%	*58%*	46%
United Kingdom	18%	3%	*48%*	16%
France	28%	8%	*47%*	11%
Japan	50%	25%	*53%*	18%
Australia	25%	26%	*37%*	23%
Canada	50%	15%	*49%*	39%
China	20%	13%	*19%*	36%
Spain	10%	3%	*29%*	16%
Sweden	13%	17%	*33%*	14%
Italy	0%	0%	*61%*	52%
South Korea	0%	11%	*48%*	42%
Netherlands	0%	8%	*38%*	11%
Russian Federation	20%	67%	*53%*	21%
Switzerland	100%	0%	*75%*	29%
Turkey	15%	50%	*13%*	23%
India	33%	29%	*38%*	13%

TABLE A5.6. Percentage of international science collaborations on fossil energy of non-U.S.–based institutions with U.S.-based institutions on the 7 top-ranked fossil energy technology journals.

Similar analysis has been conducted for international scientific collaborations in renewable energy (Table A5.5) and fossil energy (Table A5.6). The results show that the decrease of the percentage of international collaborations in renewable energy and fossil energy technologies are not as uniform as in the case of nuclear energy technology. First, the variety in levels of international collaborations with the United States in these areas is much higher. For example, China's collaborations with the United States on renewable energy ranged between 3 % and 36 % of all its international collaborations, while its collaborations on fossil energy ranged between 13% and 26 % of all its international collaborations. However, the percentages for some countries are much higher than in the case of nuclear energy. For example, the data in Table A5.6 suggests that the United States has very strong and continued collaborations on fossil energy with countries like Germany, France, Japan, Australia, and Canada. Such strong ties do not exist for renewable energy collaborations yet. Furthermore, the data shows how the percentage of international collaborations is highly dependable on the structure of the international collaboration network. For example, it seems that because most countries collaborated a little bit more in 2005, the overall percentages become much higher.

Determinants for international cooperation in science

How do scientists decide to collaborate with others? If we know this, we can devise a government strategy that supports their decisions. However, there is no simple matrix that can be used to determine which countries might be interesting partners for international cooperation. Our analysis has shown that none

FIGURE A5.9. Countries' fossil energy consumption and scientific publications in top 7 international fossil energy journals in 2006. The size of the bubble is proportional to the number of institutional collaborations that U.S. organizations had with each of the countries in 2009.

of the conventional decision criteria[31] for international cooperation map onto the actual practices of international scientific collaborations.We also examined the extent to which U.S. research institutions collaborate with other countries around the world (see Figure A5.9).

31 We compared three different determinants for international scientific collaborations for the year 2009: (1) the percentage of clean energy production in 2005 (both percentage-wise and in absolute value); (2) the R&D expenditure in percentage of GDP in 2005; and 3) the number of publications by a country in 2005. The year 2005 allows for a lag time between the decision to collaborate (assuming to be 2005) and the time that the paper is published (assuming to be 2009).

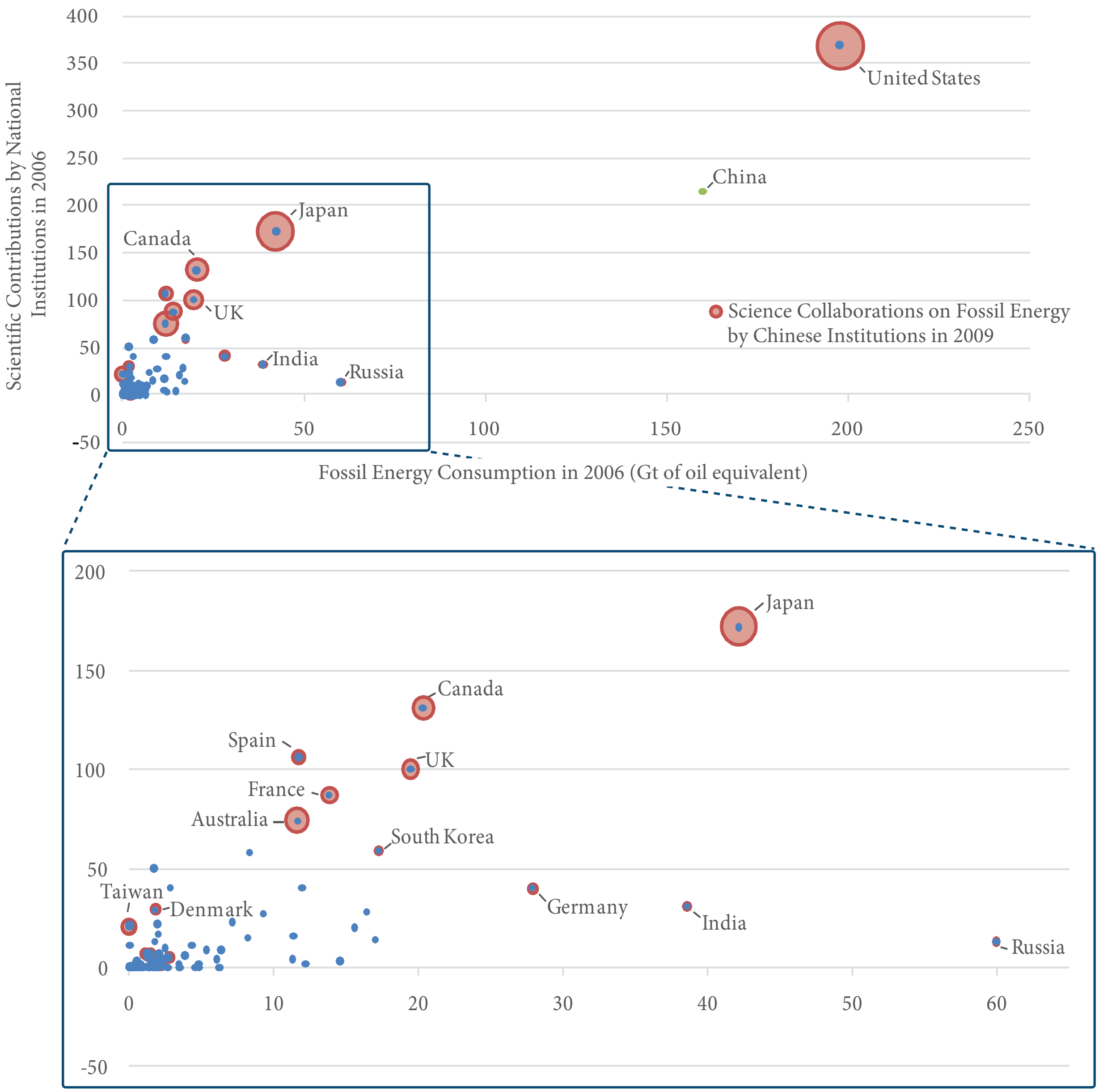

FIGURE A5.10. Countries' fossil energy consumption and scientific publications in top 7 international fossil energy journals in 2006. The size of the bubble is proportional to the number of institutional collaborations that Chinese organizations had with each of the countries in 2009.

This analysis shows that U.S. fossil energy research institutions collaborate with almost all countries that have both high levels of publications in previous years and fossil energy consumption. In other words, a combination of some of these characteristics provides a good indication of countries that are of interest for collaboration. However, the results also show that if you increase the number of indicators, the list of countries that are of interest grows fairly quickly and therefore it provides less guidance for prioritizing collaboration activities among countries.

We have conducted a similar analysis for collaborations by Chinese institutions. Figure A5.10 shows the same analysis of international science collaborations on fossil energy technology by Chinese institutions. The extent of international collaborations is much lower with a total of 150 collaborations versus 379 collaborations by U.S. institutions. However, Figure A5.10 shows that although the number of countries and the intensity of collaborations by Chinese institutions is lower, they have established a network of collaborations that includes all countries that have large fossil energy consumption and are highly represented within previous scientific work on fossil energy. In other words, Chinese institutions have access to a similar size network for international scientific collaborations as U.S. institutions.

A5.2.2. Database on international interfirm R&D activities

International cooperation has also increased, specifically with regard to R&D allocations at corporate levels (Archibugi and Iammarino 1999; Hagedoorn 2002; Carlsson 2006). Some studies look at firms internationalizing the R&D activities outside their homebase (Patel and Vega 1999; Gammeltoft 2006), while others specifically look at international partnership between firms from different countries (Hagedoorn 2002). These studies have shown that, in general, there has been a strong rise in international R&D expenditure and newly established R&D partnerships between 1975 and 1990, but that the growth has leveled off afterwards (Hagedoorn 2002). However, there is no information about international interfirm R&D partnerships on energy technology innovation.

Based on the MERIT-CATI database, developed by Prof. Hagedoorn, we attempted to analyze patterns of international interfirm R&D partnerships on energy technology innovation. The CATI database is a relational database, which contains information on cooperative agreements between independent (industrial) partners which are not connected through (majority) ownership. The CATI database includes

Energy supply R&D activities	Energy-intensive process R&D activities	Energy-intensive product R&D activities
• Electrical equipment in the heavy electrical equipment sector; • Nuclear power in the heavy electrical equipment sector; • Turbines and generators in the heavy electrical equipment sector; • Other (New Forms of Energy) in the heavy electrical equipment sector.	• Biotechnology in oil recovery and mining applications in the energy sector; • Oil refining, bulk petrochemicals, and synthetic materials in the chemical sector; • Fertilizer and pesticides in the chemical sector; • Industrial gases in the chemical sector; • Engineering activities in the petrochemical sector; • Exploration, drilling, and mining.	• ICT technology in transistor applications; • Aircraft engines; • Automotive engines; • Household appliances and white goods in the consumer electronics sector; • Lamps and picture tubes in the consumer electronics sector; • Batteries in the consumer electronics sector.

Table A5.7. Categorization of technology fields in the CATI database into energy-relevant R&D activities.

only those arrangements that include the transfer of technology, joint research, or joint ventures in which new technology is received or at least one of the partners has some R&D program.

Limitations

The CAMIT database is based on Thomson Reuters database, augmented with information from newspapers, journal articles, company annual reports, *Financial Times Industrial Companies Yearbooks* to name a few. As previously mentioned, the database contains all R&D activities and these activities are classified according to technology fields for R&D alliances, whereas partner companies might come from different industry sectors (for example, an electronics firm with a heavy electrical equipment manufacturer). Table A5.7 shows how we have categorized the technology fields within the CATI database into three different energy-relevant R&D activities: 1) energy supply R&D activities, 2) energy-intensive process R&D activities, 3) and, energy-intensive product R&D activities.

Results

These results show that international interfirm R&D partnerships have not substantially increased over the last 36 years. Furthermore, there is little difference between the various sectors associated with energy, although R&D partnerships in energy supply activities are overall lower than in the other sectors. Although the number of new R&D partnerships per year is modest (the total number of R&D partnerships ranged between 350 and 700 per year between 1984 and 1998 (Hagedoorn 2006)), energy R&D partnerships form a substantial part with between 30 and 70 partnerships per year. Over the total period, the number is considerable with 288 R&D partnerships in the energy supply sector, 637 R&D partnerships

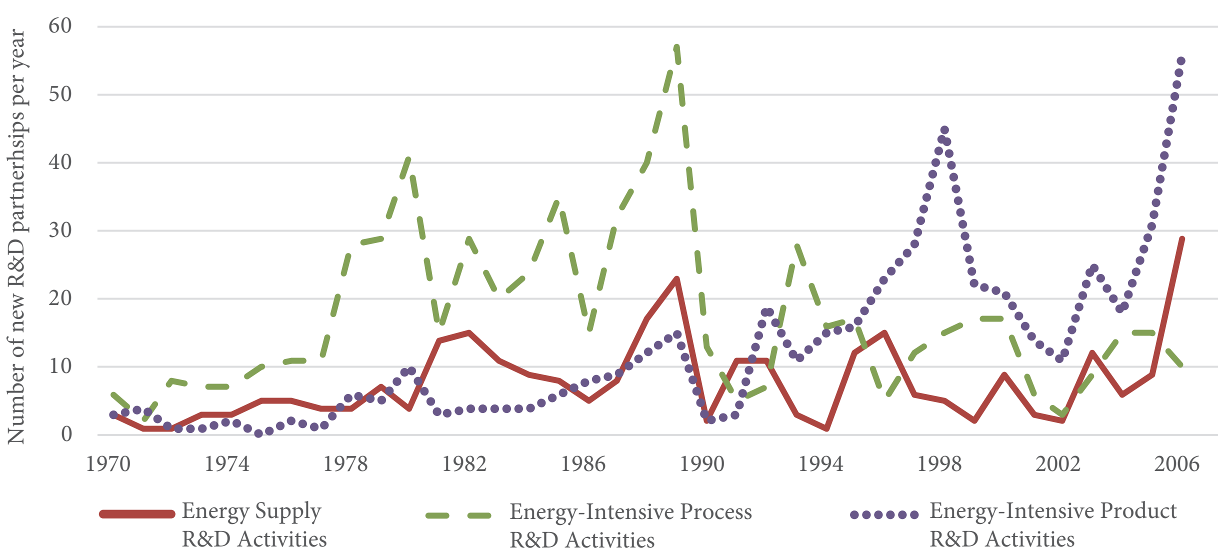

FIGURE A5.11. New international interfirm energy R&D partnerships between 1970 and 2006 (based on the CATI database by Prof. Hagedoorn).

in the energy-intensive processing industry and 460 R&D partnerships in the energy-intensive product industry. Furthermore, there is a shift from R&D partnerships in the energy-intensive processing industry to R&D partnerships in the energy-intensive product industry, while the R&D partnerships in the energy supply industry remain constant but low ranging between 0 and 10 new partnerships per year.

A5.2.3. Database on IEA Implementing Agreements

Soon after the inception of the International Energy Agency in November 1974, the IEA started to promote collaborative projects with the goal to reduce dependency upon oil, and achieve improved long-term security of energy supplies. Four technology areas for international cooperation were identified: 1) fossil fuels, 2) renewable energy forms, 3) controlled thermonuclear fusion, 4) and, technology applications in the end-use sector (IEA 1987), and this categorization still exists today. Activities range from basic studies through laboratory instruments to the development of databases to demonstration projects.

International collaboration projects are organized in the form of Implementing Agreements (IAs), which provide the basis for interested parties to undertake energy technology research, development, and deployment activities (IEA 2007). Since the Framework for International Energy Technology Co-operation of 2003, restrictions for non-member countries of the OECD to be involved in Implementing Agreements have been eliminated (IEA 2003). However, in most cases participation of OECD non-member countries needs to be approved by IEA's Committee on Energy Research and Technology (CERT). Each IA signatory designates a representative to sit on the board of directors (Executive Committee) that governs the work of the Agreement as well as of its joint projects (IEA 2010). Every year, the Executive Committee has to hand in an annual report, and every five years the Executive Committee must request an extension from CERT and its Working Parties. This extension is based on a report by the Executive Committee on their past accomplishments, and their strategy for the future. In addition, the IA is reviewed according to its structural and managerial performance, its performance, and its value to innovation and the other IAs, Working Parties, CERT, and the IEA Secretariat. Besides the five-yearly reviews, the IEA secretariat also publishes the most significant achievements on the IEA web pages, the OPEN Bulletin, and very two years in the Energy Technologies at the Cutting Edge publication.

Each IA is subdivided into Annexes, which are often (but not always) shorter-term projects with a specific goal within the framework of the IA. A country needs to sign the IA if it wants to participate in an Annex, but it is not obliged to engage in all Annexes (some IA's mandate that member countries sign up to at least one of the Annexes). Each member country of an Annex designates one or more Contracting Parties (private or public entities) to the Annex. Since 1996, participants in an Annex that are not designated by a member country are called Sponsors, and they need to be approved by the CERT (Bramberger 2004). Each Annex has one (or sometimes two) Operating Agent, which is one of the Contracting Parties responsible for managing and coordinating the Annex and which has to be approved by the

Executive Committee of the IA. Subsequently, an Annex can be subdivided into several tasks whereby different Contracting Parties or Sponsors might be assigned leadership over a particular task. IAs can be organized as cost-shared, task-shared, or different combinations depending on the activities taking place within each of the Annexes.

Our database analyzes IAs and their Annexes between 1975 and 2010. As far as possible, the database records the start and end date of each Annex, its objective, strategy, priorities, achievements, financing, and character of collaboration (task- and/or cost-shared). Furthermore, it records the Operating Agent and the member countries for each Annex. Finally, it provides a brief description of the tasks and sub-tasks within each Annex. In line with the heuristics developed and described in A5.3, the Annexes are categorized according to:

- Technology (fossil; nuclear; renewables; energy efficiency; transmission, distribution, and storage; general (unspecified) energy technologies);
- Supply chain stage (resources; conversion; use);
- Innovation stage (R&D; demonstration; deployment);
- Resources (finances; information; standards; models; knowledge; people; facilities; technology);
- Activities (fund; disseminate; coordinate; verify; transfer; develop);
- Technology characteristic (principles; components; design; manufacturing; supply chains; regulation; market support; consumers).

Each Annex can be classified in more than one category depending on the different subtasks that are taking place within the Annex.

Limitations

Data on Implementing Agreements and their Annexes is not systematically reported. For example, IEA's Ten Year Review of the Implementing Agreements (IEA 1987) provides a detailed description of the activities in each Annex, including its duration, the participating countries, and the Operating Agent. In 1992, IEA's publication described each Annex according to its objectives, achievements, review findings, conclusions, and recommendations (IEA 1992), while in IEA's 1999 publication only describes progress in the IAs and not in the individual Annexes (IEA 1999). Later publications only provide a sample of success stories, and not a systematic overview of activities in each Annex (IEA 2010).

Furthermore, it is often unclear when Annexes start and stop. There is often a lag between when an Annex is instigated, and when actual activities are taking place. Similarly, there is often a lag between the end of the activities, and the publication of a final report.

Results

In 2009, the United States participated in the most Implementing Agreements (40) followed by Canada (31), Japan (29), the United Kingdom (25), Sweden (24), Norway (24), Korea (24), and Germany (23). Figure A5.15 shows the number Annexes for each of these countries in 2009. The results show that although Germany was involved in the least number of IAs, it was the third highest participant in terms of Annexes. This suggests that there are two kinds of strategies for getting involved in IEA's Implementing

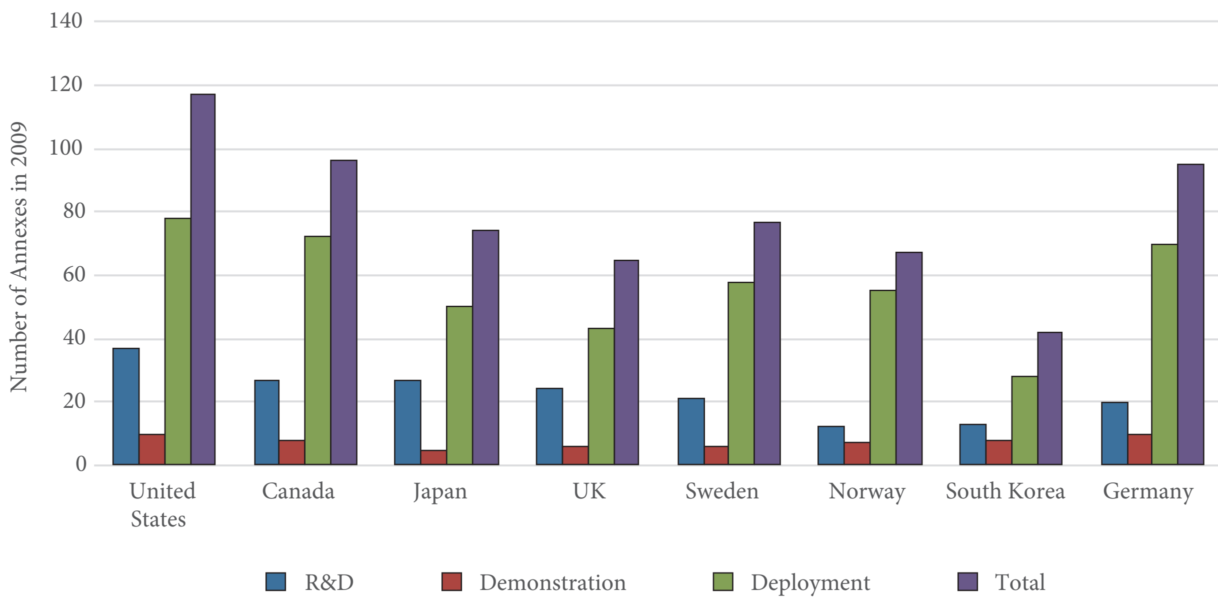

FIGURE A5.12. Number of Annexes in R&D, demonstration, and deployment for eight countries.

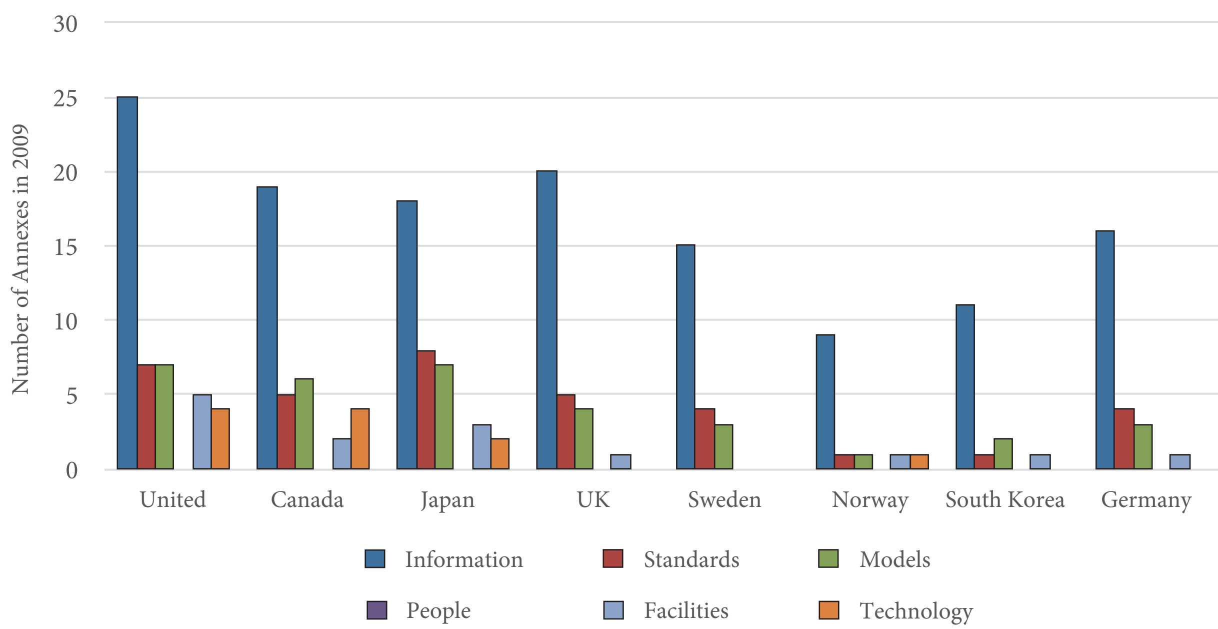

FIGURE A5.13. Breakdown of R&D activities in IEA Annexes for eight countries.

Agreements. The first strategy is to get involved in many IAs, but less involved in the actual Annexes. The other strategy is to get involved in a limited number of IAs, but get highly involved in each of the Annexes within these IAs. Furthermore, the results indicate that most Annexes deal with the deployment of technologies followed by R&D activities. The least amount of focus within Annexes is on international cooperation on demonstration projects.

Although between 16% and 33% of the countries' involved in Annexes focused on R&D activities, there is actually little to no technology development taking place in these Annexes. Figure A5.13 provides a breakdown of the activities that are taking place within the R&D Annexes for these eight countries.

The results show that most R&D activities involve information sharing followed by Annexes that focus on standards (including guidelines, testing procedures, or audit methods) and models (including simulation techniques, validation methods, or predictive system codes). Only the United States, Canada, and Japan are engaged in R&D activities that involve the development of new technologies and/or new equipment. These activities primarily take place in Implementing Agreements on fusion energy.

In our main report, we categorized different "system" elements for international ERD3 activities ranging from technology-specific collaborations (principles, components, design) to system-specific collaborations (manufacturing, infrastructure, and supply chains) to institutional-specific collaborations (market rules, regulation, and consumers).The focus on "system" elements does not seem to differ that much between countries. Figure A5.14 provides a comparison of the distribution of technology foci for all countries, the United States (40 IAs – 83 Annexes), Spain (18 IAs – 38 Annexes), and China (6 IAs – 11 Annexes). We have chosen these three countries to determine whether there is any difference in involvement depending on the number of IAs a country is involved.

The results show that most Annexes address market support, which can be in the form of providing information, creating databases, handbooks, or state-of-the-art overviews. The second largest category is design. Most Annexes do not focus on system issues, such as how to improve manufacturing, infrastructure, or supply chain issues. Furthermore, little cooperation takes place that specifically addresses or supports consumers. The results show that United States' and Spain's involvement in Annexes follow the general trend, while China is mostly involved in Annexes addressing market support issues, components, design, and regulation. It is not involved in Annexes that address manufacturing issues, supply chains, or infrastructure issues at all.

Another interesting analysis is the extent to which Annexes focus on technology for energy resource extraction (or assessment), energy conversion technologies, or energy use. Figure A5.15 shows the distribution for these three categories for all Annexes, and the Annexes in which the United States, Japan, UK, Sweden, South Korea, Spain, and China are involved.

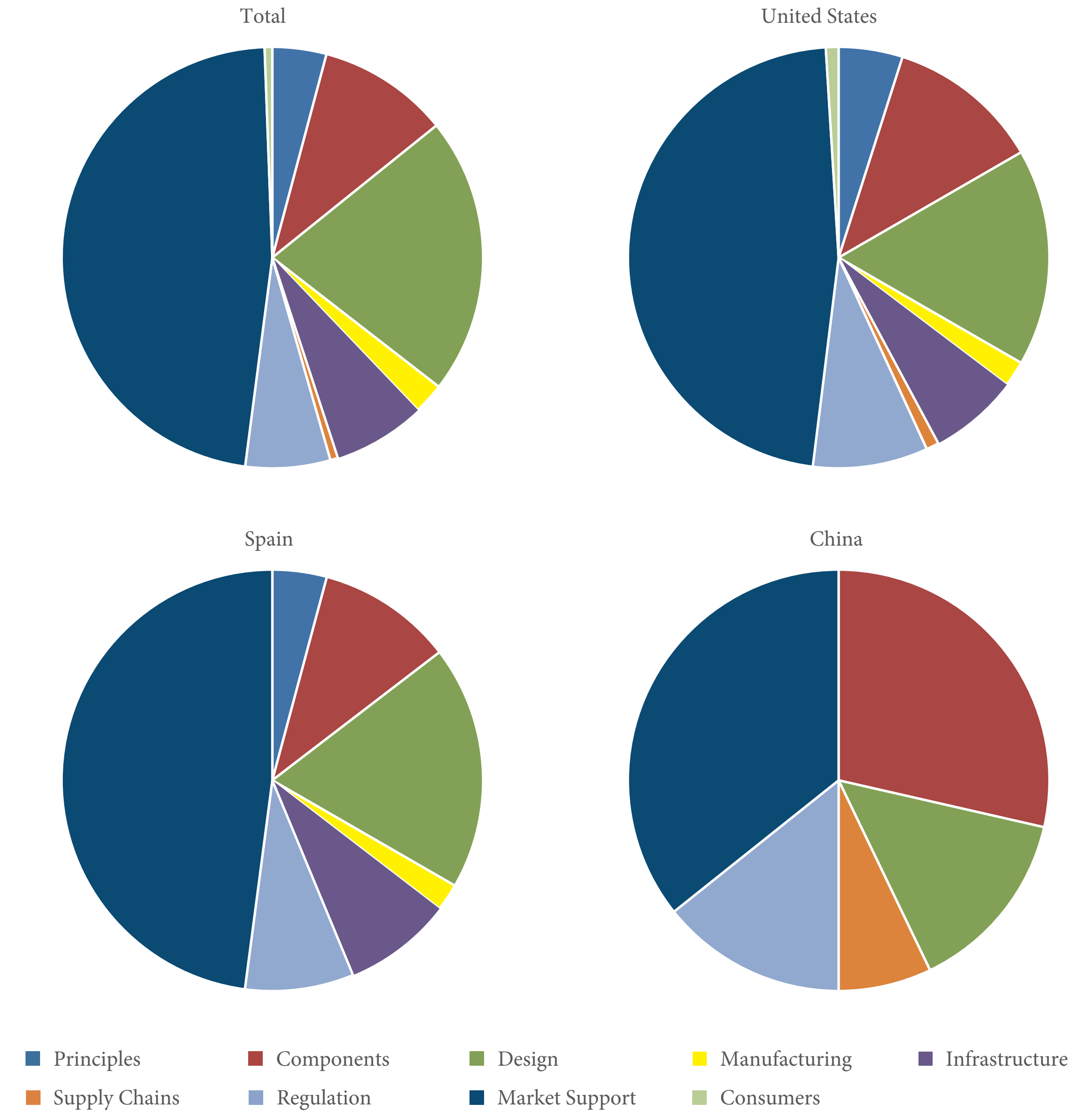

FIGURE A5.14. Distributional comparison of activities on the different "system" elements in all Annexes, and the breakdown for the United States, Spain, and China.

The results show that the distribution of what Annexes countries engage in does not differentiate according to the supply chain area. Except for newcomer China, other countries engage in 8% to 14% of their Annexes that address energy resource technologies, 40% to 54 % in Annexes that address energy conversion technologies, and 37% to 50% in energy use technologies.

The database also allows comparison between years. Figure A5.16 shows the distribution between R&D,

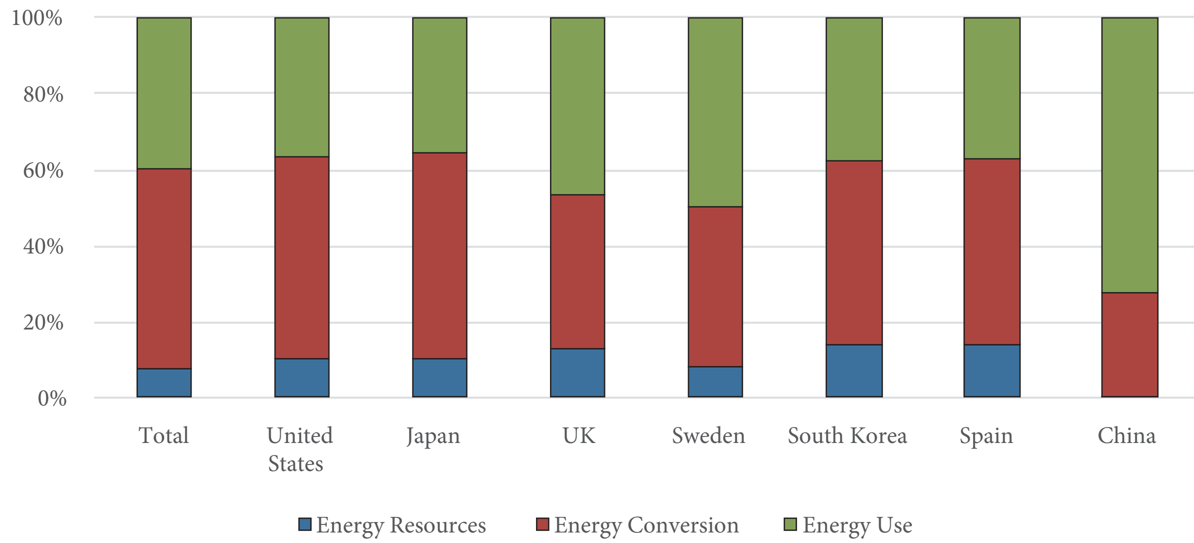

FIGURE A5.15. Distribution of energy resource, energy conversion, and energy use technologies over all Annexes, and those from the United States, Japan, UK, Sweden, South Korea, Spain and China.

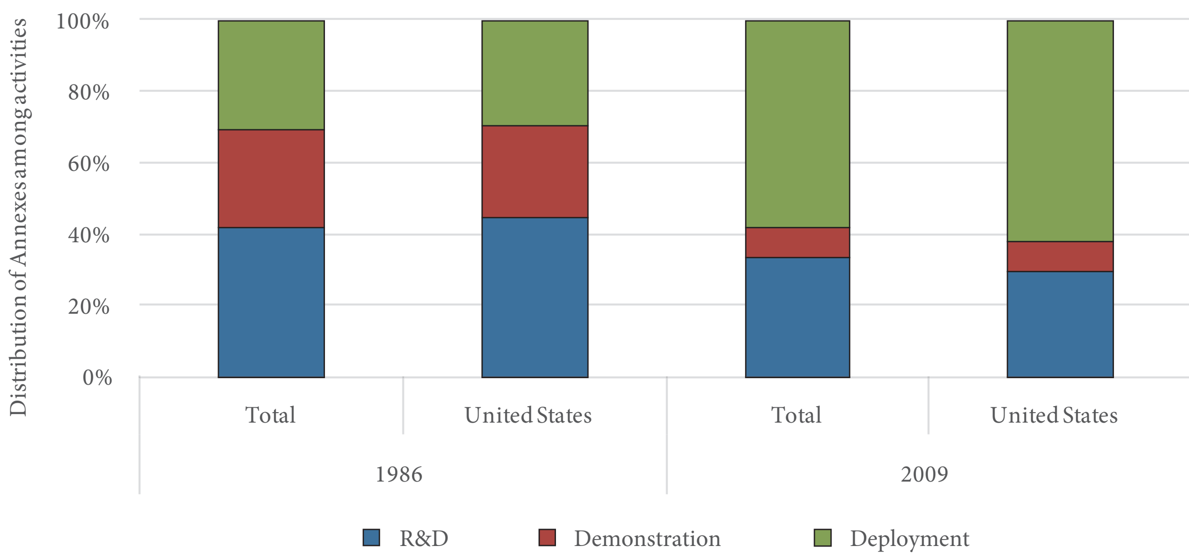

FIGURE A5.16. Comparison of the distribution of R&D, demonstration, and deployment activities in Annexes in 1986 and 2009.

demonstration, and deployment projects in all Annexes and United States' Annexes in 1986[32] and 2009. The results show that there is little difference between the overall distribution within Annexes and the United States' Annexes, but that there has been a shift away from R&D and demonstration activities to deployment activities between 1986 and 2009.

32 We have chosen 1986, because this is the year before IEA published a detailed review of all Annexes and Implementing Agreements (IEA 1987). Accordingly, we have assumed that the data on Annexes in 1986 was most up to date and accurate.

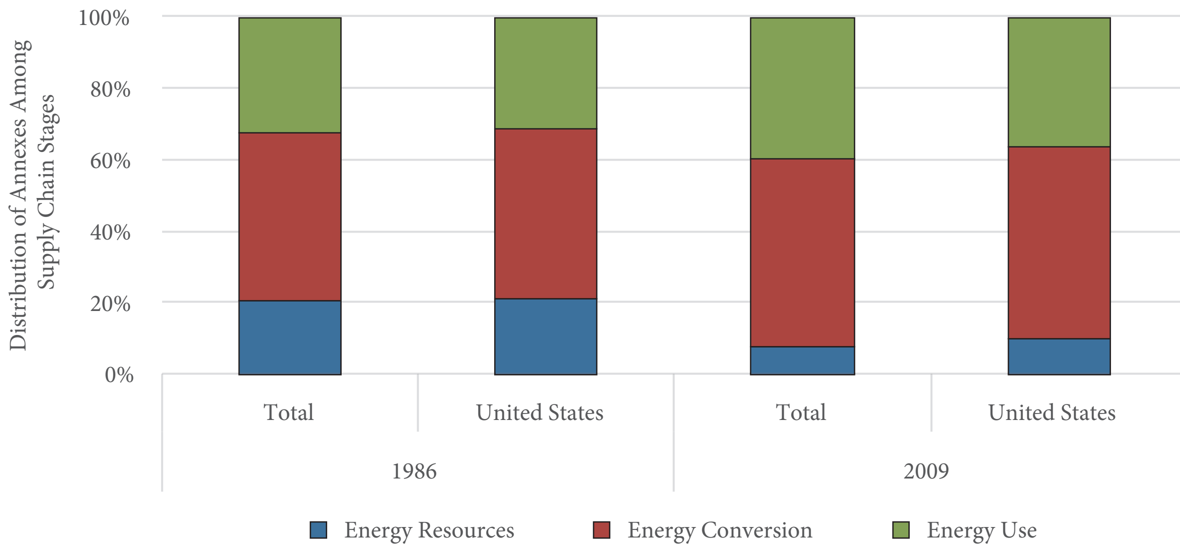

FIGURE A5.17. Comparison of distribution of supply chain focus in Annexes in 1986 and 2009.

Figure A5.17 shows a similar comparison for the distribution of Annexes according to their supply chain focus. Again, there is little difference between the distribution of all Annexes among supply chain stages and those in which the United States is involved. However, over time the focus has shifted away from cooperation activities on energy resources to cooperation on energy use. The number of Annexes focused on energy conversion technologies has increased from 47%-48% to 52%-53%.

Similar comparisons have been completed to evaluate the difference in technology focus (see Figure A5.18) and the resources involved in Annexes (see Figure A5.19).

The results show that there is surprisingly little change in the overall resources involved in Annexes between 1986 and 2009. Mostly, Annexes involve, in one way or another, exchange of information. The focus on standards grew slightly from 15% to 22%, while the focus on models, people, facilities, and technology decreased. The largest change is an increased focus on knowledge cooperation (for example, exchanging experiences, practices, design specifications, experiments) which goes a step beyond just sharing information. The focus on innovation elements has changed substantially between 1986 and 2009. In 2009, 47% of Annexes focus on cooperation that support, in one way or another, the market in comparison to 25% in 1986. Design issues were the largest focus in 1986 with 36%, but decreased to 21% in 2009. Furthermore, there is less focus on cooperations that examine principles of new technologies in 2009, and more focus on institutional aspects such as regulation and consumers.

Overall, these results suggest that the differences between various countries engaged in IEA's Implementing Agreement are smaller than the differences that have taken place in the overall shift in IEA's Annexes. The Annexes have shifted their attention from R&D activities and demonstration activities towards de-

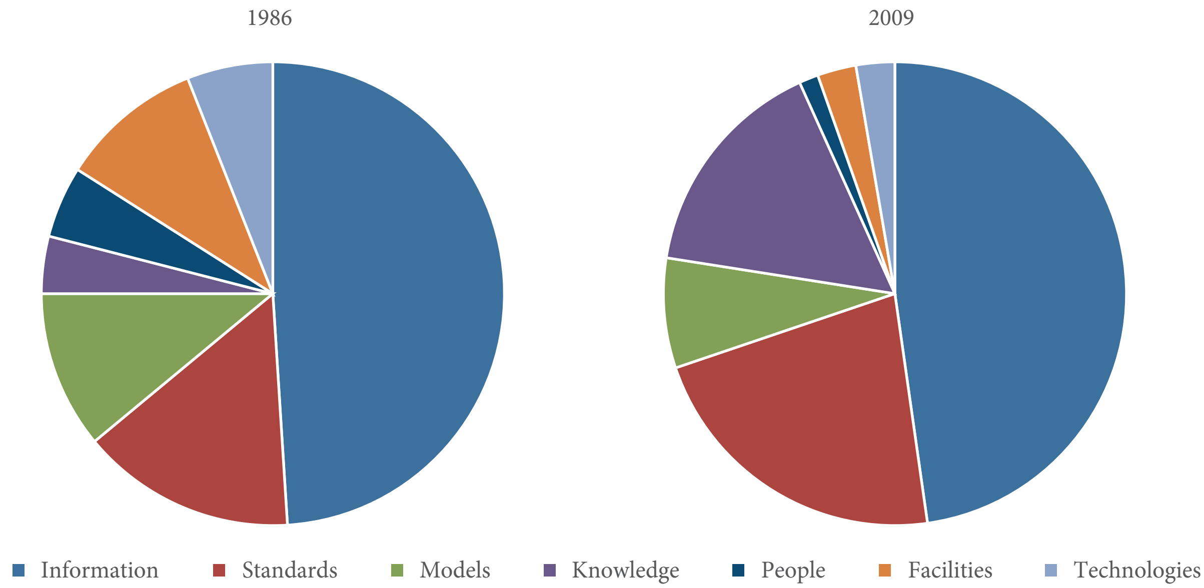

FIGURE A5.18. Comparison of resources involved in Annexes between 1986 and 2009.

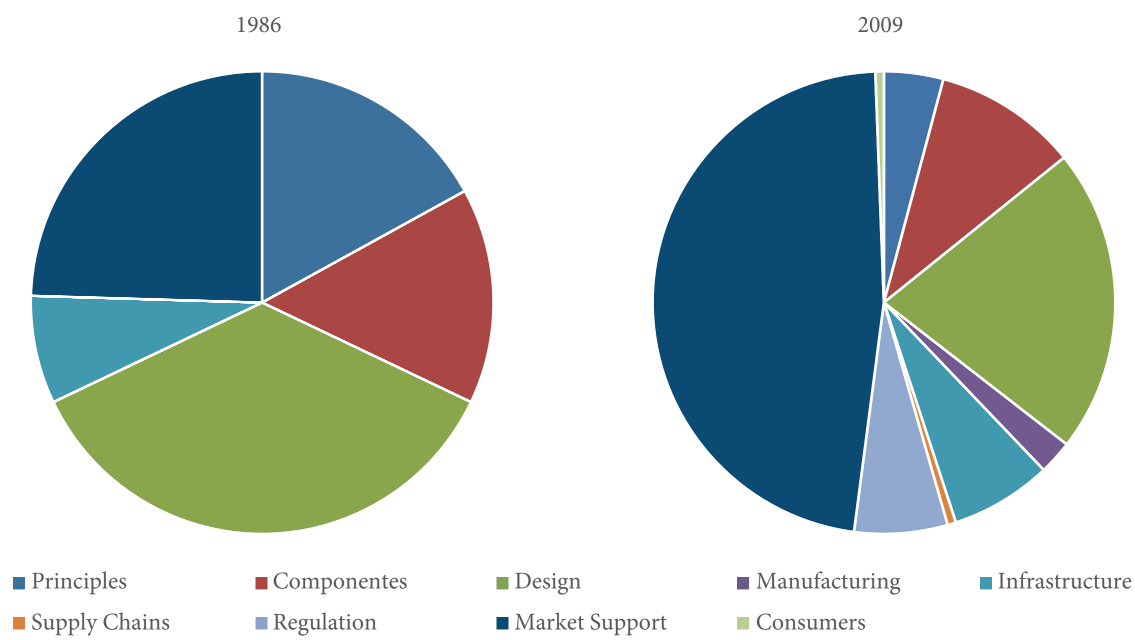

FIGURE A5.19. Comparison of technology focus of Annexes between 1986 and 2009.

ployment activities. This is also evident in the technology focus of Annexes, which has shifted away from design issues to institutional issues, such as market support and regulation. Furthermore, Annexes are more focused on activities to improve energy use than on activities that support energy resources.

A5.2.4. Results of U.S. governmental bilateral agreements

The results of this analysis are based on the preliminary version of the COMMIT database, which was developed by the Office of International Science and Technology Affairs at DOE. The April 2010 version was used for this analysis. The COMMIT database provides an overview of the country involved, the name of the agreement, and the start date of the agreement. Besides bilateral agreements on energy technology, it also includes agreements on "illicit trafficking of nuclear material" and agreements to "enhance the security of container cargo." The latter two forms of agreements are not included in the overview.

The results show that bilateral agreements are still a major platform for international cooperation. In May 2010, DOE's Program Office of International Science & Technology Cooperation had listed 218 energy-related bilateral agreements with 74 different countries (excluding any bilateral agreements with international organizations). Of these 218 bilateral agreements, 36 focused on illicit trafficking of nucle-

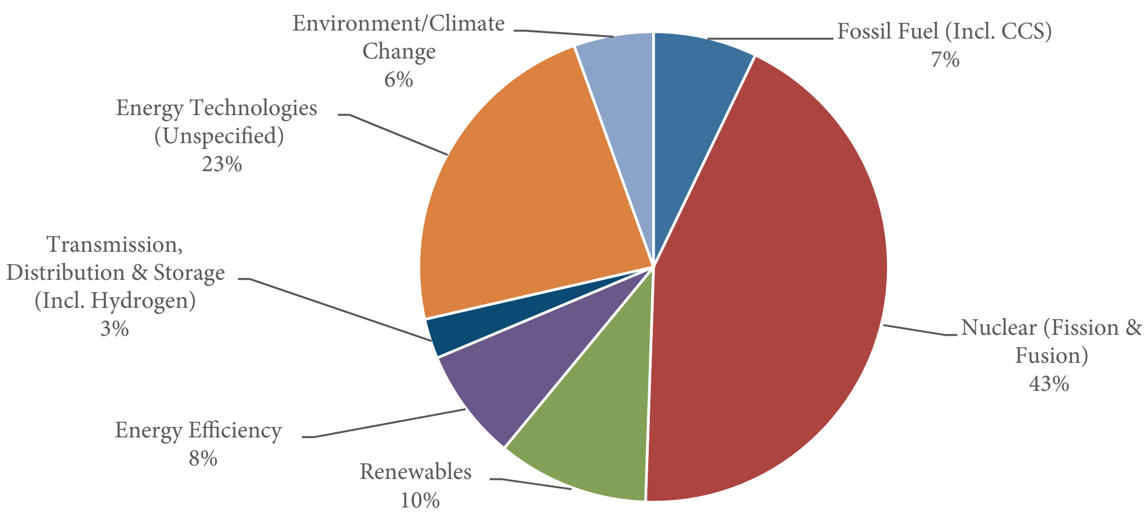

FIGURE A5.20. Categorization of U.S. bilateral agreements in energy technologies in 2010.

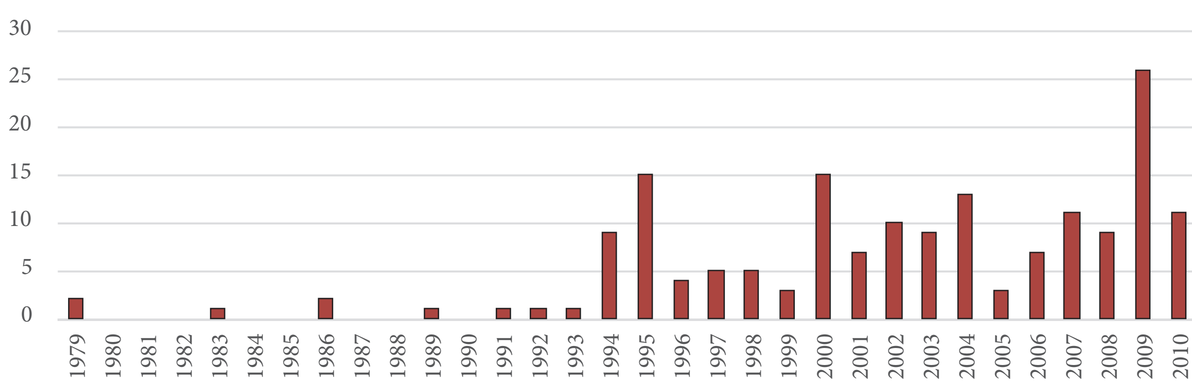

FIGURE A5.21. Year of signing of U.S. bilateral agreements on energy technologies.

ar materials and 175 agreements with 46 countries focused on energy technology cooperation. Figure A5.20 provides an overview of the distribution of bilateral agreements towards seven different energy technologies (including environment-related agreements and generic energy technology agreements).

The results show that most bilateral agreements are on nuclear energy (excluding any agreements on illicit trafficking of nuclear materials or agreements on enhancing cargo security). Generic energy technology agreements are the second largest group followed by agreements on renewable energy technologies (10%), energy efficiency (8%), and fossil energy (7%).

Most agreements (71%) that are currently in place were signed between 2000 and 2010, and 22% of the agreements have been signed in the last year and a half (2009 and up to April 2010). The longest running agreements are with China (since 1979), France (1983 and 1986), and the European Atomic Energy Community (EURATOM) since 1986.

Figure A5.22 shows the number of agreements in place in April 2010 with each country. China is the largest collaborator with the United States with 29 agreements followed by France (15), Japan (11), and the Russian Federation (11). These three countries are also the countries with which the United States has the longest lasting agreements (see Figure A5.21). In the period between 1994 and 1995, the United States signed agreements with Canada, India, and South Africa, and new agreements for each of these three countries were signed in 2009 and 2010.

In our main report, we paid specific attention to six countries (Brazil, Russia, India, Mexico, China, and South Africa) who currently consume about a third of world's energy. Figure A5.26 provides an overview of the number of agreements per country, the energy technology areas they cover, and a breakdown of the agreements for the six BRIMCS countries. The results show that there are a variety of agreements with Brazil, China, India, and South Africa. Most agreements with Russia are on nuclear energy, and there is only one generic energy technology agreement with Mexico.

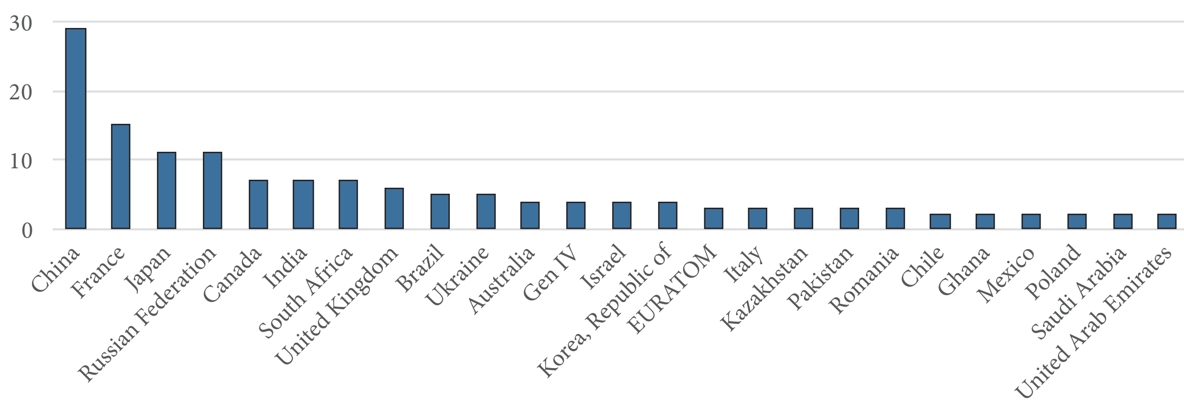

FIGURE A5.22. Countries with which the U.S. government has bilateral agreements on energy technologies.

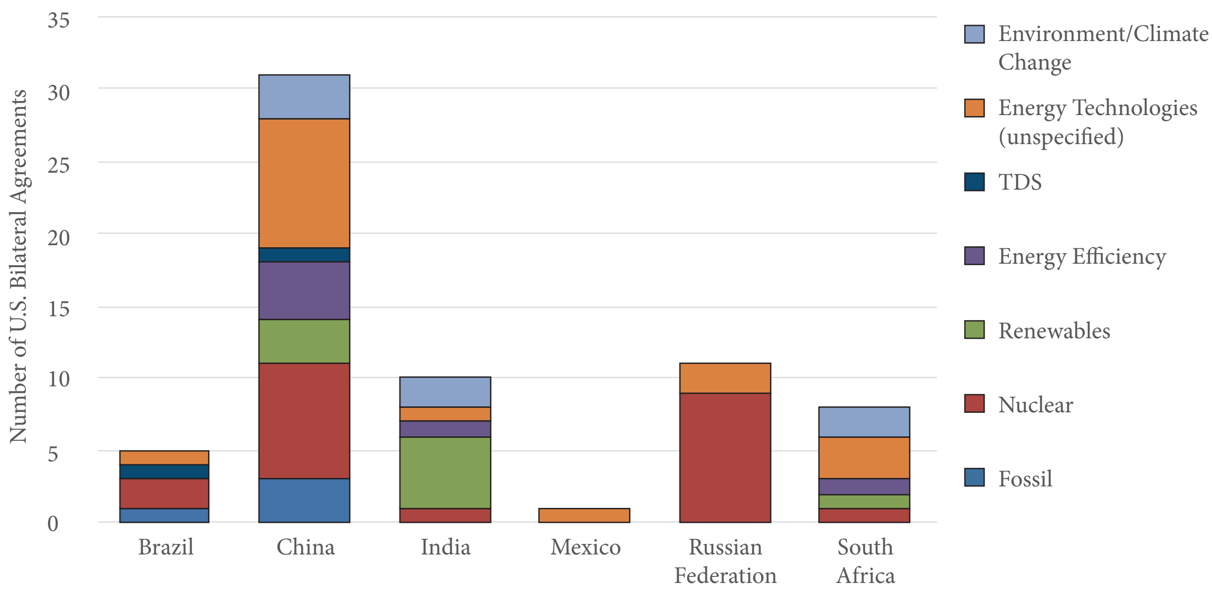

FIGURE A5.23. U.S. bilateral agreements on energy technologies with the BRIMCS countries.

We have also examined the relationship between a country's characteristics and the number of bilateral agreements signed with the U.S. government. The six country characteristics and associated proxies are:

- Foreign markets for energy technology: growth in absolute primary energy use between 1997 and 2007;
- Contribution to economic development: relative growth/decline in energy intensity between 1997 and 2007;[33]
- Energy security: absolute growth in energy imports between 1997 and 2007;
- Nuclear proliferation: absolute growth in nuclear power generation between 1997 and 2007;
- Global emissions: absolute growth in CO2 emissions between 1997 and 2007;
- Local and regional pollution: absolute growth in PM10 concentrations between 1997 and 2006.

We used the relative and absolute growth in each of these six characteristics to determine any similarities between the countries with which the U.S. government signs agreements, and their characteristics. Table A5.8 shows that the bilateral agreements signed by DOS or DOE cover the top 10 countries that provide foreign markets for energy technologies, impact energy security, contribute to global green-

33 Although there is no causal relationship between the absolute level of energy intensity and economic development, we have assumed that economic development is correlated with a more efficient use of energy resources, and therefore a relative stronger decline in energy intensity.

Absolute energy use growth 1997-2007 (kt of oil equivalent)	Relative energy intensity growth 1997-1007 (kt of oil eq./$1000 GDP (2005 PPP))	Energy imports growth 1997-2007 (kt of oil equivalent)	Absolute nuclear energy growth 1997-2007 (kWh)*	Absolute co2 emissions growth 1997-2007 (kt)	Absolute PM10 concentration growth 1997-2006 (mg/m3)
Korea, Rep.	Oman	China	Korea, Rep.	China	Albania
Russian Federation	Cote d'Ivoire	United Kingdom	Russian Federation	India	Senegal
China	Yemen, Rep.	India	China	Iran, Islamic Rep.	Guatemala
France	Jamaica	Spain	France	Saudi Arabia	Solomon Islands
Czech Republic	Iceland	Turkey	Czech Republic	Indonesia	Honduras
Ukraine	Haiti	Korea, Rep.	Ukraine	Kazakhstan	Benin
Canada	Congo, Rep.	Poland	Canada	Spain	Maldives
Brazil	Gabon	Italy	Brazil	Mexico	Costa Rica
India	Togo	Japan	India	United Arab Emirates	Argentina
Slovak Republic	Saudi Arabia	France	Pakistan	Turkey	Gabon

* For nuclear proliferation, we have only considered agreements on nuclear energy, illicit trafficking and security of container cargo.

1 agreement	2-5 agreements	> 5 agreements

TABLE A5.8. Top 10 countries for cooperation using quantitative proxies for each of the PCAST 1999 criteria. The color scale indicates the number of bilateral agreements that the United States has with each country.

house gas emissions, and might present nuclear proliferation risks. However, the U.S. government has few bilateral agreements with the some of the countries might benefit the most from cooperation to stimulate economic growth or reduce local air pollution.

This overview results in a total of 41 different countries that are of potential value for international co-operation on energy technology cooperation according to one or more of these decision criteria. Some countries (in particular, India, China, France, and South Korea) appear more than once in these rankings, but the majority of countries (27) appear only once. Furthermore, this ranking leaves out some countries, like Germany, the Scandinavian countries, Mexico or Egypt, that could be of interest to the United States for reasons outside of these six decision criteria.

We conducted a similar analysis taking into consideration the absolute value of each of these six characteristics in 2007 (the latest year for which this data was available.)[34] Table A5.9 shows the analysis based on values for 2007. The results show that the ranking changes depending on whether you use absolute values or relative growth values. In most categories, China ranks high both in terms of growth numbers and absolute values in 2007. However, the ranking of countries high in PM10 concentrations changes, and the United Kingdom drops of the ranking of energy importers. Furthermore, growth characteristics

34 Since there is no clear relationship between the absolute level of energy intensity and economic growth (since it depends on sectoral structures and environmental conditions), we will disregard the ranking based on this characteristic.

Energy use 2007 (kt of oil equivalent)	CO2 emissions 2007 (kt)	Energy intensity 2007 (kt of oil eq./$1000 GDP (2005 PPP))	PM10 concentration 2006 (mg/m3)	Nuclear energy 2007 (kWh)*	Energy imports 2007 (kt of oil equivalent)
China	China	Congo, Dem. Rep.	Uruguay	France	Japan
Russian Federation	India	Uzbekistan	Sudan	Japan	Germany
India	Russian Federation	Turkmenistan	Mali	Russian Federation	Korea, Rep.
Japan	Japan	Mozambique	Bangladesh	Korea, Rep.	Italy
Germany	Germany	Togo	Niger	Germany	India
Canada	Canada	Zambia	United Arab Emirates	Canada	China
France	United Kingdom	Trinidad and Tobago	Pakistan	Ukraine	France
Brazil	Korea, Rep.	Ukraine	Egypt, Arab Rep.	Sweden	Spain
Korea, Rep.	Iran, Islamic Rep.	Iceland	Iraq	United Kingdom	Turkey
United Kingdom	Mexico	Kazakhstan	Saudi Arabia	China	Ukraine

TABLE A5.9. Ranking of countries based on absolute levels of six indicators associated with energy-relevant country characteristics in 2007.

give higher rankings to Eastern European and Asian countries, such as the Czech Republic, Slovak Republic, Ukraine, Poland, the Baltic countries, Turkmenistan, Azerbaijan, and Kazakhstan.

A5.2.5. Results of U.S. overseas development aid on energy

The analysis of U.S. overseas development aid (ODA) on energy projects is collected through OECD's Creditor Reporting System database on overseas development aid (OECD 2010). This database provides information about donor and recipient countries, the activities involved in the aid, the type of aid, the financial resources provided, and the organizations involved. Data on U.S. financial aid is collected from 2000 to 2009. Only ODA projects categorized under "energy" have been considered. The OECD's Creditor Reporting System provides a unique identification number to each project to reduce the possibility of double counting. The data was corroborated with a database developed by AidData, which provides data on development finance and foreign aid (AidData 2010). In the latter database, we have analyzed projects categorized under "energy generation and supply" projects.

OECD's creditor reporting system database includes data on ODA from six main U.S. departments and agencies. In 2009, most funding came from the U.S. Agency for International Development (USAID) ($162 million), the Department of Defense ($129 million) for energy projects in Afghanistan and Iraq, the Department of Energy (DOE) for projects related to nuclear energy ($38 million). The Millennium

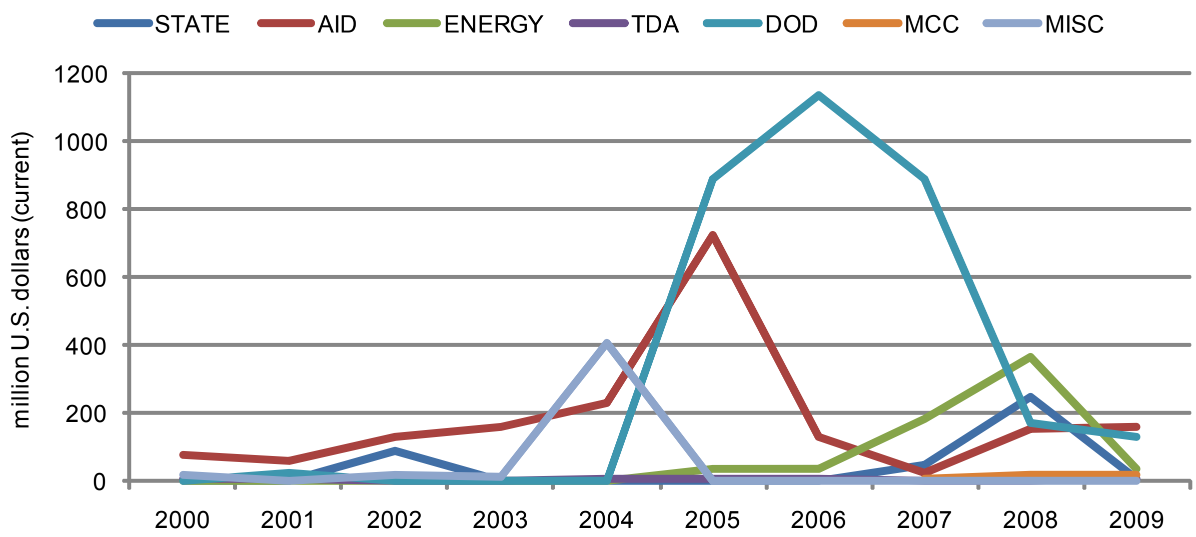

FIGURE A5.24. Overseas development aid for energy projects by six U.S. agencies (MISC = miscellaneous) between 2000 and 2009.

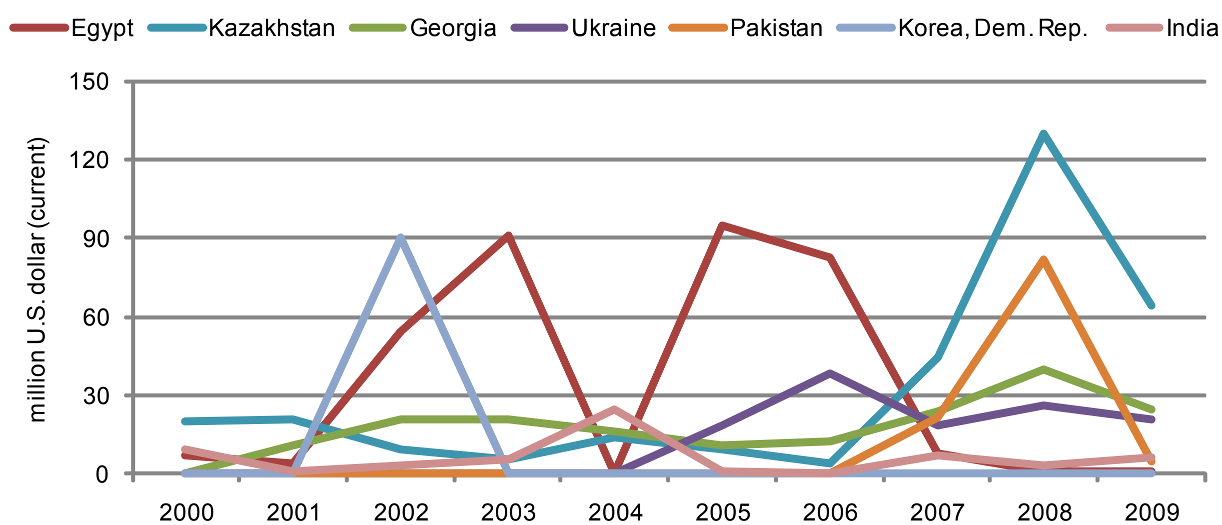

FIGURE A5.25. Overseas development aid to energy projects in the seven highest receiving recipients (except Iraq and Afghanistan).

Challenge Corporation's (MCC), the Department of State, and the U.S. Trade and Development Agency (TDA) funded respectively $22 million, $9 million, and $7 million on energy projects. However, Figure A5.27 shows that the amount of money spent by each of these agencies fluctuated very strongly between 2000 and 2009. From 2005 to 2007, DOD provided between $886 and $1131 on energy projects in Iraq and between $4 to $15 million on energy projects in Afghanistan. Furthermore, AID provided $542 million on energy projects in Iraq. The trend of large amounts of money also occurred in 2002 ($90 million to North Korea through State), 2004 ($386 million to Iraq), and 2008 ($129 million to Kazakhstan through DOE and $240 million to Iraq through State). [35]

As mentioned in the previous paragraph, most overseas development aid is incidental and has been going to countries like Iraq and Afghanistan. Figure A5.25 shows the allocation of U.S. overseas development aid to the other seven countries that received the highest amount. The graph shows that Egypt has received the highest amount of funding for energy projects, although the funding fluctuates per year. Kazakstan and Georgia have received a constant stream of ODA over the 2000-2009 period, and Ukraine's ODA has been comparably steady since 2005.

The allocation of overseas development aid to energy projects differs per agency. Between 2005 and 2009, DOD mainly provided ODA for energy projects in Iraq and Afghanistan (with $4 million and $0.5 million to Albania in 2001 and 2006, respectively). Most of State's ODA over the period between 2000 and 2009 went to North Korea in 2001 ($90 million) and to Iraq in 2008 ($240 million). The two other recipients for ODA by State were India ($11 million) and China ($1.5 million), with some smaller amounts of ODA going to Uzbekistan, Nicaragua, and Chile. Furthermore, State funded international energy cooperation activities under APP. Since 2007, MCC has provided ODA to three counties; Georgia ($39 million over three years), El Salvador ($3.5 million), and Tanzania ($7.8 million). AID, DOE, and TDA provided ODA for the largest range of countries. Between 2000 and 2009, TDA, DOE, and

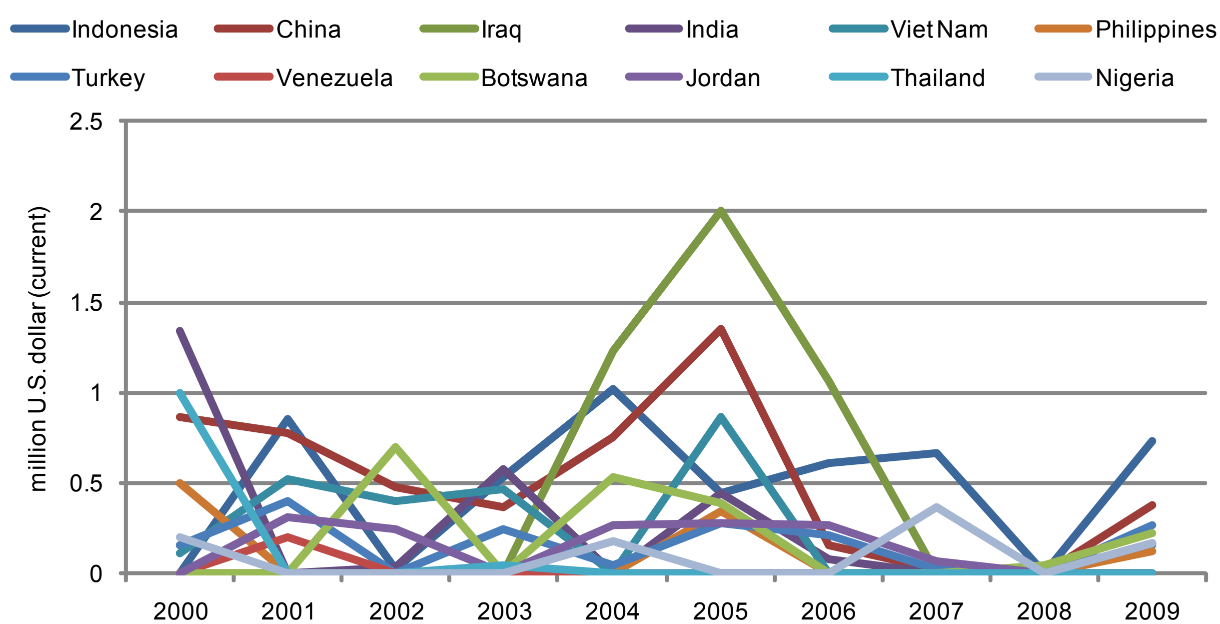

FIGURE A5.26. TDA funding for energy projects in the 12 largest recipient countries between 2000 and 2009.

35 All data is in annual U.S. dollars.

AID provided ODA for energy projects to 79, 71, and 50 different countries and/or regions, respectively.

Figure A5.26 shows the allocation of ODA by TDA to their 12 largest recipients. The total funding of TDA is much lower than the other agencies, but the variety of countries that are supported are larger. The recipients receiving the highest amount of ODA between 2000 and 2009 were Indonesia ($5.6 million), China ($4.3 million), Iraq ($3.7 million), and India ($2.8 million). There is no single country that has received ODA from TDA for all of the nine years (Turkey received ODA eight out of the nine years).

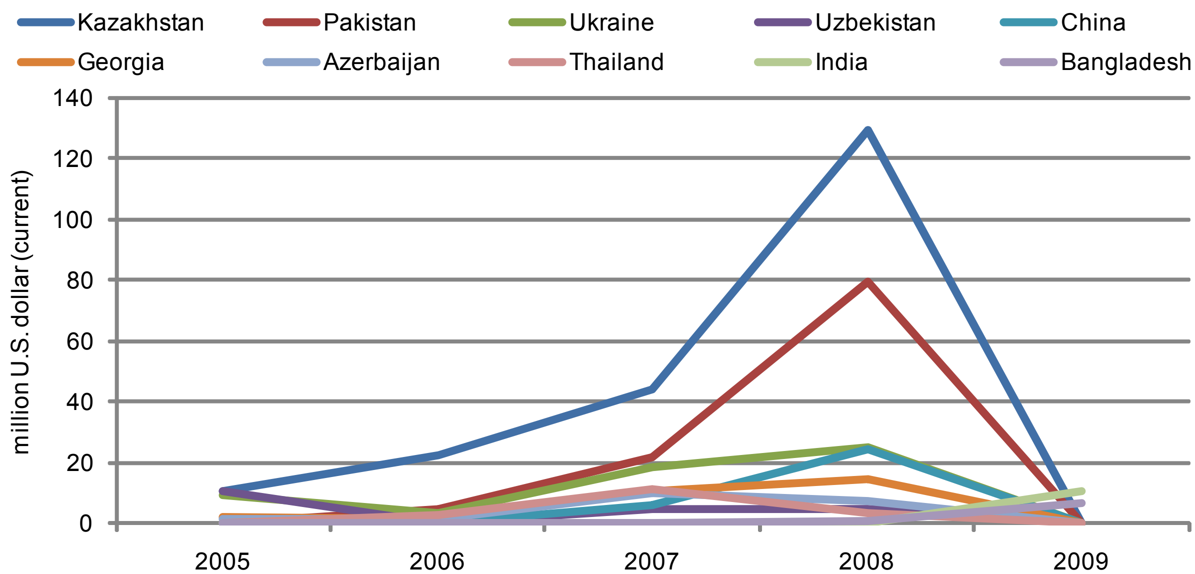

Figure A5.27. DOE funding for energy projects in its eight largest recipient countries between 2005 and 2009.

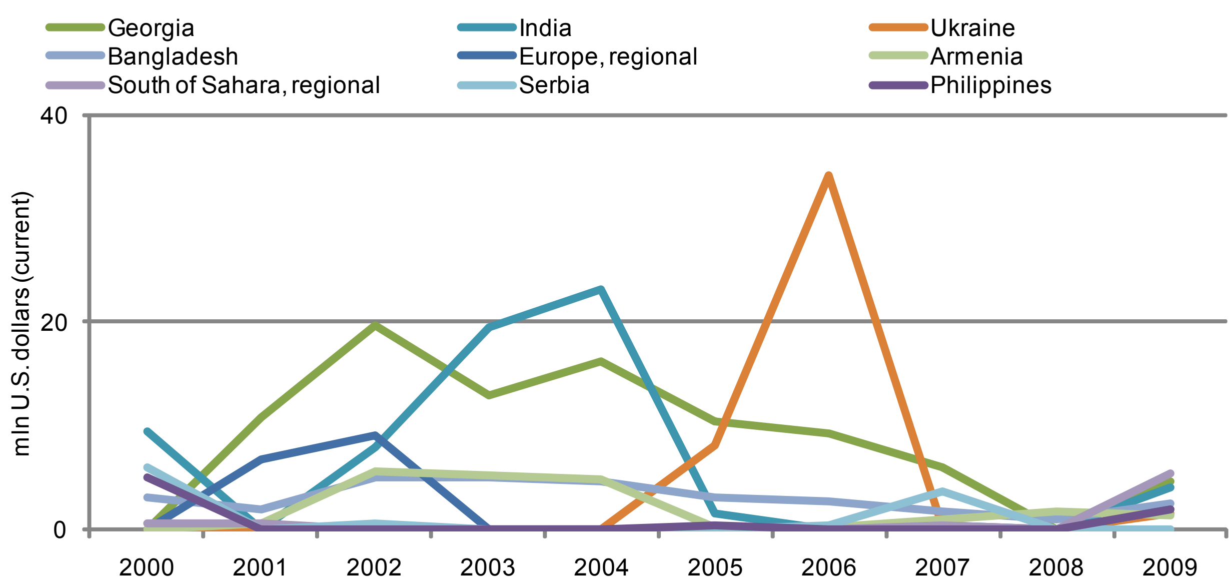

FIGURE A5.28. USAID funding for energy projects in the 12 largest recipient countries/regions (excluding Iraq, Afghanistan, and Egypt) between 2000 and 2009.

Data on DOE's allocation of ODA is only available since 2005. All of the DOE allocations went to nuclear energy projects in two broad categories: 1) energy policy and administration management, or 2) nuclear power plants. The first category includes projects on safe handling and use of nuclear materials for civilian projects, while the latter category included projects that reduced global nuclear material threat, protected nuclear materials, or engaged in global security. Figure A5.27 shows the allocation for DOE for its eight largest recipients. Kazaksthan is the highest recipient with $188 million over 5 years followed by Pakistan ($101 million), Ukraine ($58 million), Uzbekistan ($33 million), and China ($30 million). In 2009, ODA funding for the top eight recipients dropped, while ODA funding for India ($10 million) and Bangladesh ($7 million) were increased.

Iraq and Afghanistan are two of the three largest recipients of ODA by AID. Since 2003, Iraq and Afghanistan have received $693 million and $290 million, respectively. The other large recipient of ODA for energy projects is Egypt, which has received ODA consistently from 2000 to 2009, except for 2004. In total, Egypt received $338 million between 2000 and 2009. In comparison, the next countries not in a war situation that received the highest amount of ODA were Georgia ($100 million), India ($49 million), Ukraine ($45 million), and Bangladesh ($30 million). Figure A5.28 shows the allocation of funding by AID, excluding any ODA to Iraq, Afghanistan, and Egypt.

The data shows that ODA allocations are not very consistent, which can be explained by the project-nature of AID's activities. Europe received relative high levels of funding in 2001 and 2002, India in 2003 and 2004, and Ukraine in 2006.

Using data between 2000 and 2009, we also attempted to analyze whether funding is associated with

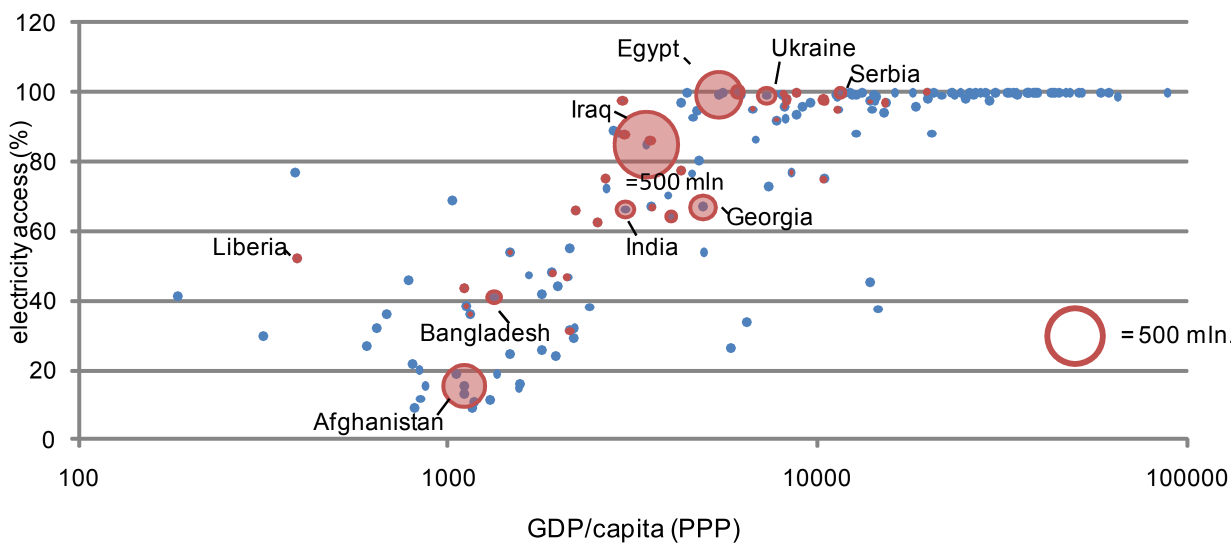

Figure A5.29. Cumulative support for energy projects by USAID between 2000 and 2008. The size of the red bubbles is proportional to the total expenditures.

particular country characteristics. First, we determined whether there was a relationship between ODA funding, the economic status of a country (in GDP/capita), and their electrification (% of electricity access). Figure 5.5 shows all countries in the world positioned according to the percentage of its population with access to electricity and its GDP per capita. The red dots show the cumulative expenditure on USAID energy projects in these countries between 2000 and 2009. According to USAID guidelines (USAID 1984; 2009), three objectives for international cooperation on energy technology are the provision of modern energy access to the poor, the support for economic development, and the improvement of environmental conditions. Following the first two objectives, it seems that USAID should be mostly collaborating with those countries that are poor and have low percentages of electricity access (countries located in the bottom left corner of Figure A5.29.). However, Figure A5.29 shows that many of the countries that fit those two criteria do not receive any support from USAID. Instead, the majority of energy projects take place in four countries: Iraq, Afghanistan, Georgia, and Egypt.

Figure A5.30 shows the relationship between ODA funding by USAID and a country's number of people without electricity access (in millions) and their economic level (GDP/capita). As expected, there is a loose relationship between the economic level of a country and the number of people that have access to electricity, where higher levels of economic development are related to lower numbers of people without electricity access. USAID's allocation of ODA funding for energy projects does not exclusively target underdeveloped countries with low electricity access. Figure A5.30 shows that on the one hand there is a cluster of countries that receive ODA for energy projects with a high number of citizens without electricity access in South-East Asia (India, Bangladesh, Pakistan, and Indonesia), and on the other

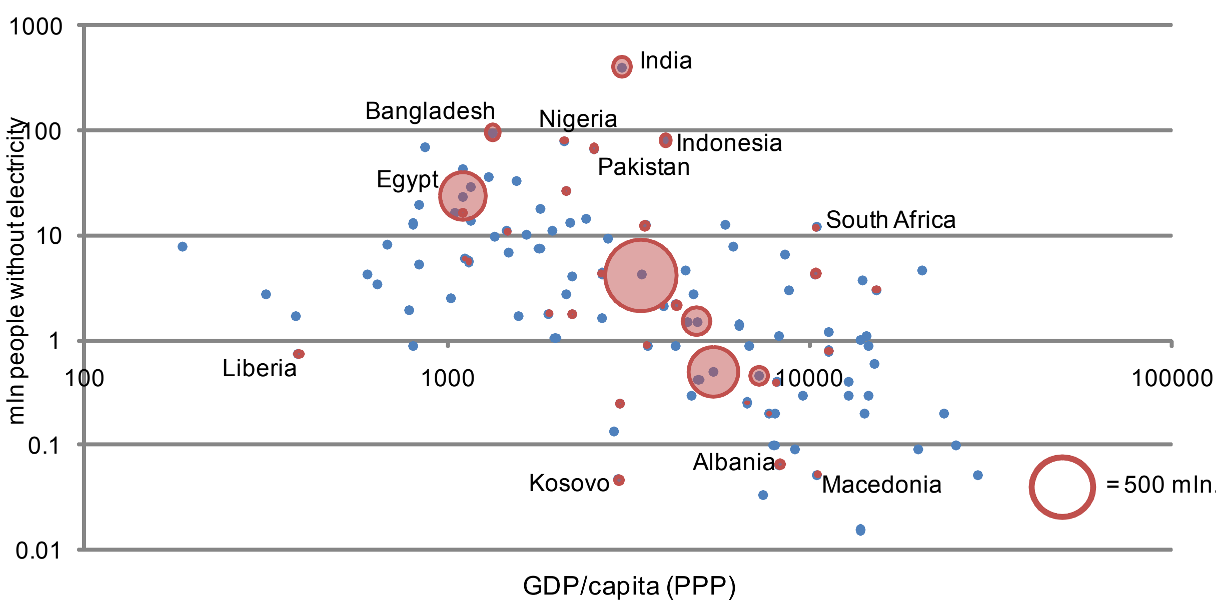

FIGURE A5.30. Relationship between ODA funding for energy projects by AID and a country's growth in energy intensity and its number of people without electricity access.

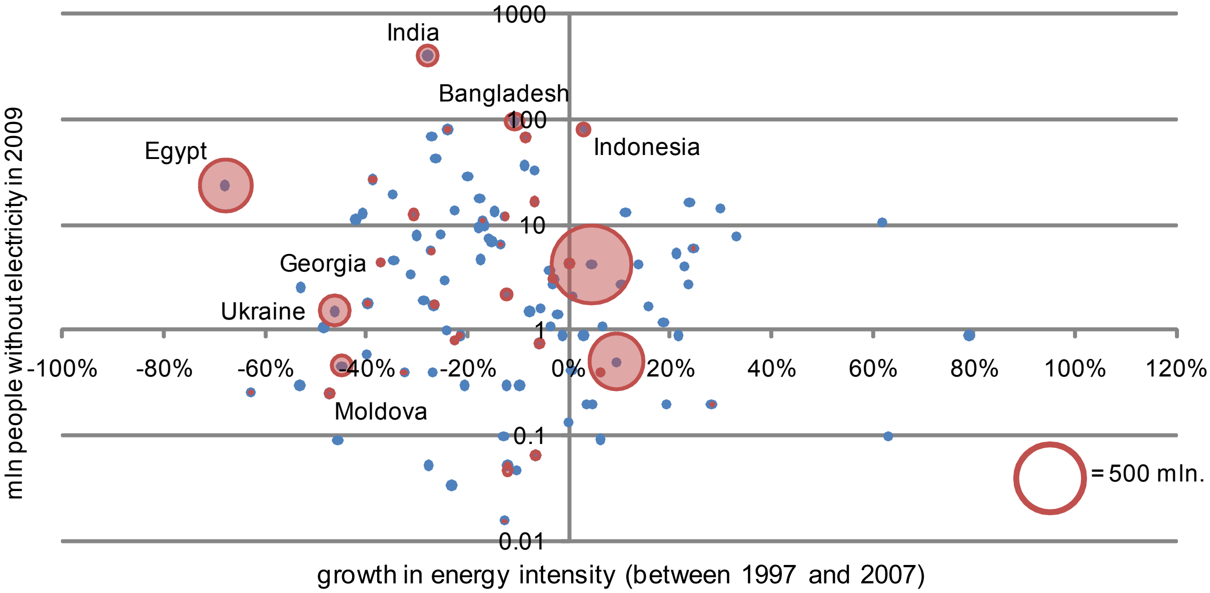

FIGURE A5.31. Relationship between ODA funding for energy projects by USAID between 2000 and 2009 (the size of the bubble), and a country's growth in energy intensity between 1997 and 2007 (horizontal access)and its number of people without electricity access in 2009.

hand a group of countries that have higher than average economic development and very low number of citizens without electricity access in South-East Europe (Kosovo, Albania, Macedonia).

Another way of examining this data is to see whether it is possible to measure the extent that ODA funding for energy projects might have made a difference in increasing the economic output within a country. Figure A5.31 shows the relationship between the size of ODA funding, the number of people without electricity access within a country,[36] and the growth in energy intensity between 1997 and 2007 (in percent). The expectation would be that those countries that have received ODA funding for energy projects throughout the 2000 to 2009 period improved their national energy efficiency (reflected in a decrease of their energy intensity measured in kiloton of oil equivalent/GDP in $1000 dollar PPP). This data shows that most countries that received ODA funding by USAID decreased their energy intensity. Jamaica and Haiti had the highest increase in energy intensity despite ODA funding (28% and 25%, respectively), while Thailand, Indonesia, Egypt, Iraq, and Honduras showed an increase in energy intensity (between 1% and 9%) despite ODA funding. Iraq's increase in energy intensity can be explained by the war, but it is interesting to observe that Egypt's energy intensity increased despite it being the second largest recipient of ODA funding for energy projects by USAID.

Finally, we can compare the recipients of the highest amount of funding by each agency. Table A5.10

36 Ideally, we would have liked to plot the growth/decline in the number of people without electricity access over the period between 1997 and 2007.

U.S. AID	State	DOE	U.S. TDA	DOD	MCC
Iraq	Iraq	Kazakhstan	Indonesia	Iraq	Georgia
Egypt	North Korea	Pakistan	China	Afghanistan	Tanzania
Afghanistan	India	Ukraine	Iraq	Kazakhstan	El Salvador
Georgia	China	Uzbekistan	India	Armenia	
India	Uzbekistan	China	Viet Nam	Uzbekistan	
Ukraine	Nicaragua	Georgia	Philippines	Ukraine	
Bangladesh	Tuvalu	Azerbaijan	Turkey		
Armenia	Chile	Thailand	Venezuela		
Serbia		Philippines	Botswana		
Indonesia		Dom. Republic	Jordan		

TABLE A5.10. Top 10 recipients of ODA funding by U.S. agency between 2000 and 2009.

shows a direct comparison between the top ten recipients for each of the six agencies. Excluding Iraq and Afghanistan, this overview shows that India, China, Uzbekistan, Georgia, and Ukraine received ODA funding from three different U.S. agencies. Armenia and the Philippines both received ODA funding from two different U.S. agencies.

A5.2.6. Results of U.S. import and exports of energy technologies

The analysis of U.S. import and export of energy technologies has been based on two separate databases: the Trade DataWeb provided by the U.S. International Trade Commission (USITC 2010) and the United Nations Commodity Trade Statistics Database (UN COMTRADE 2010). Both SITC codes and NAICS

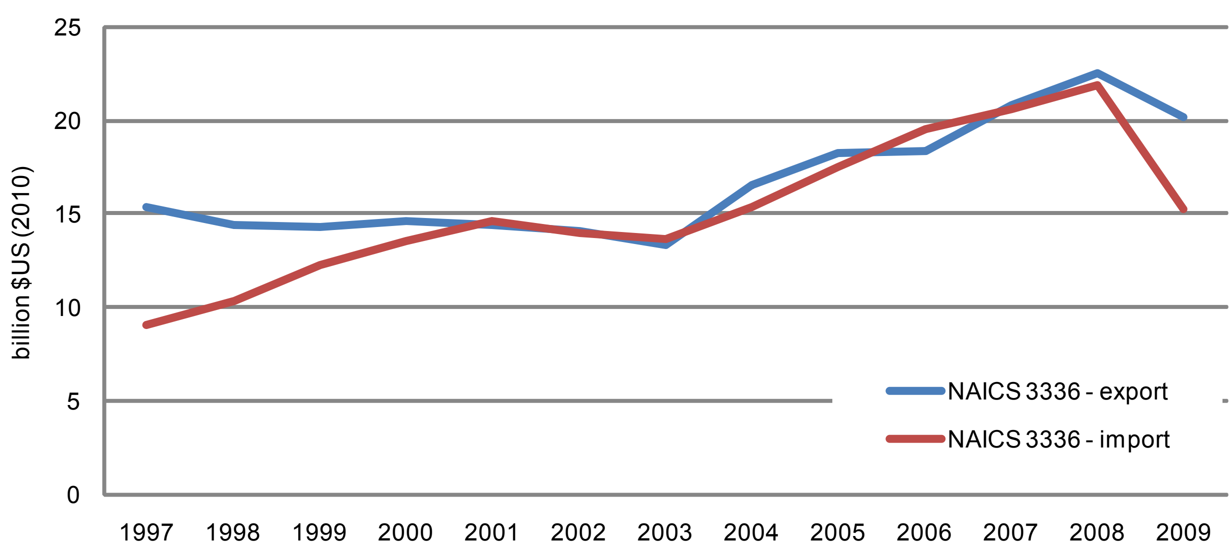

FIGURE A5.32. Import and export of engines, turbines, and power transmission equipment (NAICS 3336) to the United States.

codes are used to provide a longitudinal overview of import and export of energy technologies to and from the United States.

An analysis of the United States' import- and export of energy technologies, in terms of normalized value, shows that have been growing steadily since 1990, particularly after 2000 (except for 2009). This indicates the international flow of energy technologies is growing and that government initiative to support the deployment of energy technologies outside their own borders is important to stimulate energy technology innovation. Figure A5.32 shows the monetary value (normalized for 2010) for the import

Figure A5.33. Number of countries from which U.S. companies import and export steam turbines (HTS code 8406) between 1989 and 2009.

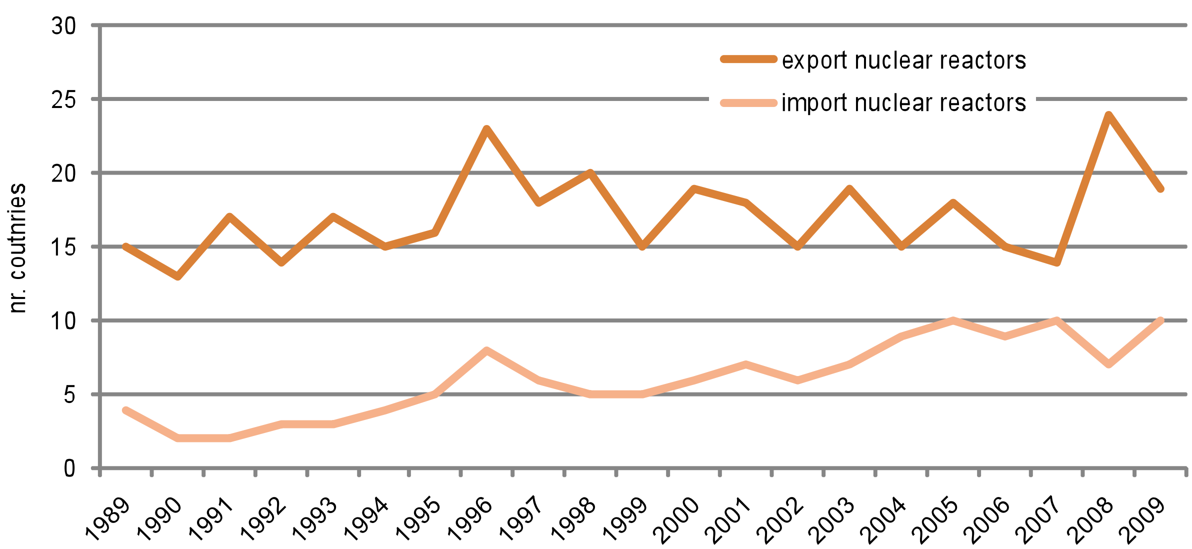

FIGURE A5.34. Number of countries from which U.S. companies import and export nuclear reactors and parts thereof (HTS code 8401) between 1989 and 2009.

and export of products under the NAICS code 3336, which includes "engines, turbines, and power transmission equipment."

These figures show two phenomena. First, the import and export value of energy technologies is increasing within the United States. Second, the United States almost imported almost as much engines, turbines, and power transmission as it exported. Not only did the imports and exports value increase, but the number of countries with which U.S. companies traded increased as well. Figure A5.33 shows the number of countries with which U.S. companies have been trading steam turbines (HTS code 8406). The data shows that both the number of export countries (from around 35 to 60) and the number of countries from which U.S. companies imported steam turbines has increased (from around 10 to 20). A similar trend, at least for the number of import countries, can be found for the import and export of nuclear reactors, and parts thereof (HTS code 8401). Figure A5.34 shows that the number of countries from which the United States imported nuclear reactor parts has increased from about four to 10 during this time span, while the number of countries to which nuclear reactor parts were exported has increased from around 15 to 20.

The previous three figures showed that the value and number of countries that engage with import and export of energy technologies with the United States has increased. However, the import and export flows have not increased uniform for each energy technology. Figure A5.35 and Figure A5.36 shows in some more detail the trade balances for specific energy technologies.

Figure A5.35 shows that the trade balance for all four energy technologies was positive before 2000 (except for hydraulic turbines in 1989 and steam engines in 1990), but after 2000 the trade balance showed much more fluctuations. Since 2000, the United States' value of import of steam boilers is higher than

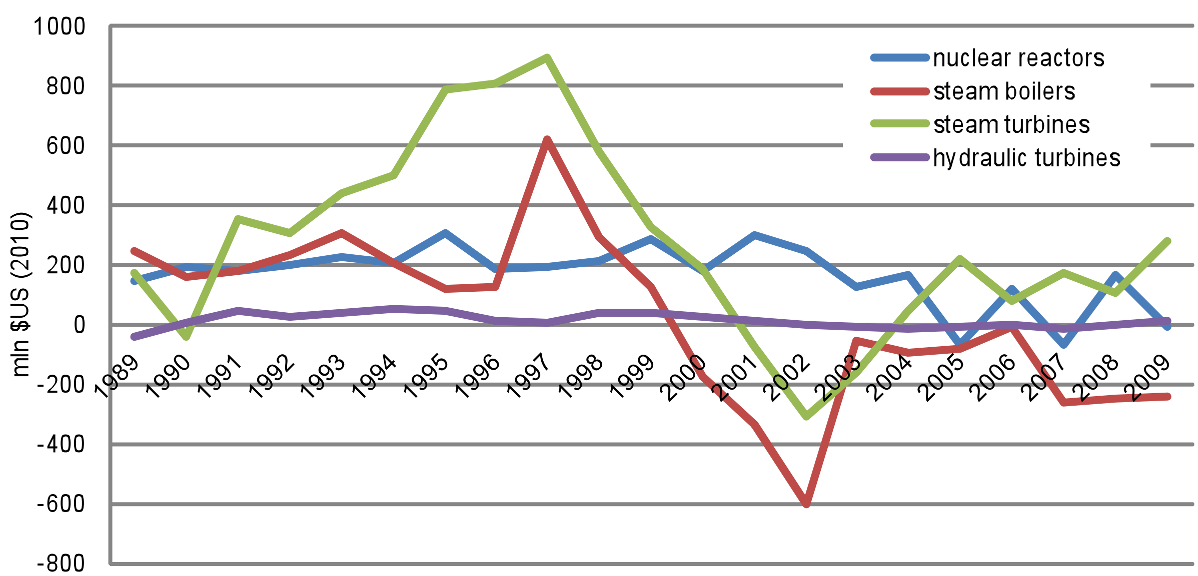

FIGURE A5.35. U.S. trade balance for nuclear reactors (HTS code 8401), steam boilers (HTS code 8402), steam turbines (HTS code 8406), and hydraulic turbines (HTS code 8410) between 1989 and 2009.

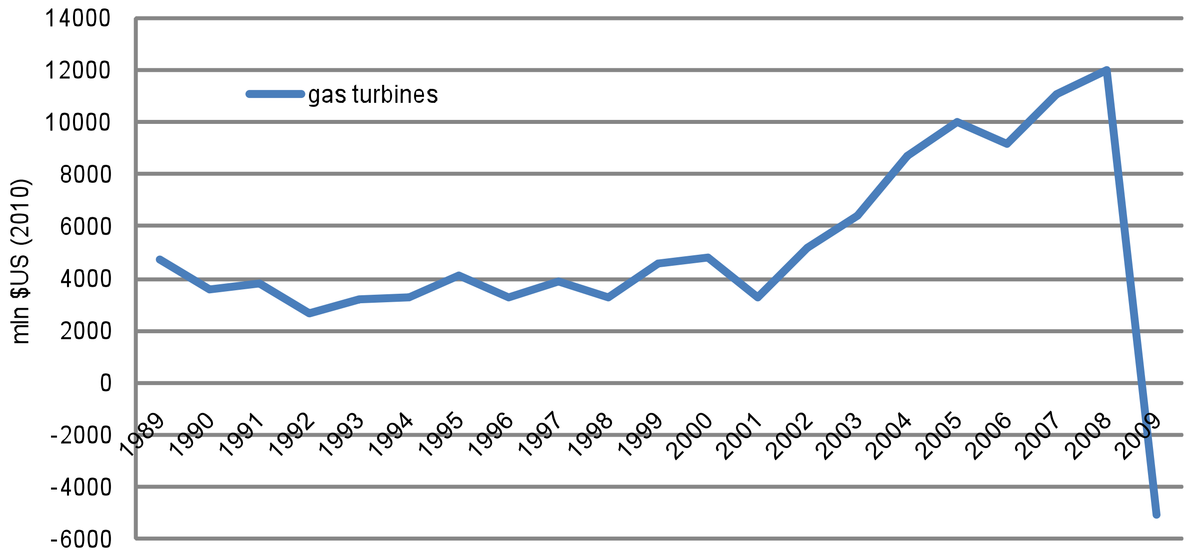

Figure A5.36. U.S. trade balance for gas turbines, including turbojets (HTS code 8411) between 1989 and 2009.

its export. Also, the import value of steam turbines and nuclear reactors (and parts thereof) has in several years become higher than its export value. Figure A5.36 shows the trade balance for gas turbines, which is, and has been, one of the most important export energy technologies. In 2009, however, the United States' trade balance for gas turbines was negative, which might be explained by the financial crisis. Despite the financial crisis, this data suggests that the dependency of the United States on energy technologies from foreign countries has increased.

A5.2.7. Results of stakeholder analysis of international and national programs on carbon sequestration

The U.S. government has at least four international cooperation activities on clean fossil energy and carbon, capture and storage: (1) several Implementing Agreements within the IEA; (2) the Clean Fossil Energy Task Force within the APP; (3) the Carbon Sequestration Leadership Forum (CSLF); (4) and, the Carbon Capture, Use, and Storage (CCUS) action group within CEM. On a national level, the U.S. government supports seven regional carbon sequestration partnerships (administrated by DOE),[37] as well as several other councils and associations that receive direct or indirect support by the U.S. government. Using the websites for each of these national and international platforms, we have extracted the number of U.S. stakeholders involved in each of these platforms. A U.S. stakeholder was defined as a U.S. company involved in the partnership, or an international organization from which the contact person (as mentioned on the website) was located in the United States. The analysis was conducted on

37 http://fossil.energy.gov/sequestration/partnerships/index.html, accessed December 2010.

Name	Website/References	Nr. of U.S. stakeholders involved
Global CCS Institute	(Global CCS 2011)	62
APP – Clean Fossil Energy	http://www.asiapacificpartnership.org/english/pr_fossil_energy.aspx	3
IEA –fossil fuel annexes	(IEA 2010)	8
CSLF	http://www.cslforum.net/cslfstake	92
U.S. Carbon Sequestration Council	http://www.uscsc.org/members.asp	10
Midwest Regional Carbon Sequestration Partnership	http://216.109.210.162/Mrcsp.aspx	38
West Coast Regional Carbon Sequestration Partnership	http://www.westcarb.org/team	98
Southeast Regional Carbon Sequestration Partnership	http://www.secarbon.org/ - partners	83
Southeast Regional Carbon Sequestration Partnership – Coal Research Group	http://www.energy.vt.edu/secarb/partners.asp	28
Midwest Geological Sequestration Consortium	http://sequestration.org/partner.htm	42
Plains CO_2 Reduction Partnerhsip	http://www.undeerc.org/PCOR/about/partners.aspx	107
Big Sky	http://www.bigskyco2.org/about/partner	70
Southwest Regional Partnership	http://southwestcarbonpartnership.org/AboutSWP.aspx	47
Texas Carbon Capture and Storage Association	http://txccsa.org/corp_members.cfm	9
U.S. Carbon Sequestration Council		10

TABLE A5.11. National and international platforms for carbon capture and storage and the number of U.S. stakeholders involved.

16 December 2010. Table A5.11 shows the name of the platforms, their websites and the number of U.S. companies or U.S. organizations involved.

In total, there are 532 organizations active in the 7 regional partnerships and other national associations and councils on carbon capture and storage. In comparison, there are 165 U.S. organizations involved in the four international platforms on carbon capture and storage. However, in both cases, there are several U.S. organizations that participate in more than one national or international platform.

If we count the number of unique participants in each of these different platforms, then there are 139 unique U.S. stakeholders involved in each of these four platforms[38] ranging from consultancy firms, to

38 Some stakeholders are involved in more than one international agreement or partnership, so they are counted only once.

foundations, to energy companies, to city councils. For national platforms, there are 430 unique U.S. stakeholders involved in these regional sequestration partnerships. Many of the U.S. organizations in national platforms are universities, local councils, and planning commissions. However, there are many local and national industries and consultancy firms involved in national platforms also.

Of the 139 stakeholders involved in international agreements, only 48 are involved in national partnerships. Interestingly, many of the international consultancy firms with U.S. establishments were involved in international platforms, but not in national platforms. Examples of such companies are Baker and McKenzie, Booz & Co., Booz Allen Hamilton, Boston Consulting Group, Ernst & Young, KPMG, and PriceWaterHouseCoopers.

A5.3. The Case of United States-India International ERD3 Cooperation

International ERD3 cooperation has intensified under the Obama administration, although many of the foundations were laid under the Bush administration (Scherr, Jaiswal et al. 2011). In November 2009, building upon the U.S.-India Energy Cooperation agreement signed in May 2005 under the Bush administration, Prime Minister Manmohan Singh and President Barack Obama launched a new Green Partnership, which included a MOU to enhance cooperation on Energy Security, Energy Efficiency, Clean Energy and Climate Change, a MOU on Solar Energy and a MOU on Wind Energy. Furthermore, an Indo-U.S. Clean Energy Research and Deployment Initiative was launched (Office of the Press Secretary 2009). In the following year, their commitment was reaffirmed during Obama's visit to India by embracing the U.S.-India Partnership to Advance Clean Energy (PACE) at the heart of its Green Partnership, initiating a U.S.-India Energy Cooperation Program, and the signing of a MOU on Unconventional Natural Gas Cooperation (Office of the Press Secretary 2010). PACE will receive $50 million over 5 years in U.S. funding and an equal amount of Indian funding, and is subdivided into two parts. DOE is responsible for a program of activities on research collaborations (PACE-R) and USAID is coordinating a program involving deployment cooperation (PACE-D). So far, DOE is in the process of establishing a Joint Clean Energy Research and Development Center with funding for "Building Energy Efficiency," "Second Generation Biofuels," and "Solar Energy"[39] (DOE 2011). PACE-D includes a range of projects involving USTDA and DOC (supporting trade development activities), OPIC, and EXIM (mobilizing clean energy investments in India), State (assisting shale gas diplomacy and design). USAID's program will focus on: (1) scaling up energy efficiency technology and practices, including smart grids; (2) advancing commercial renewable energy technologies; (3) support for supply-side efficiency of existing fossil power generation; (4) and, enhancing greenhouse mitigation planning and programs

39 Solar Energy will receive a total of $US 12.5 million funding over five years, while the other two programs will receive $US 6.25 million. A similar distribution of funding will be available through the Government of India for the Indian counterparts to this center.

The description of existing international ERD3 activities between the United States and India demonstrates how the decisions to cooperate are affected by historic settings, by a large number of different departments and agencies, and by a mixture of political and practical pressures. In the main report, we showed a more analytical approach to arrive at a set of potential areas for international ERD3 cooperation. This approach was based on a set of comparative frameworks that compared the existing energy technology innovation policies, institutions and priorities in both the United States and India. Interestingly, both the political process and the analytical approach end up with similar areas of cooperation, which demonstrates that even a more analytical approach is able accommodate for some of the political and practical pressures that drive international ERD3 cooperation negotiations. The next six sections will discuss these areas in more detail, and display some of the U.S. and Indian government policies and institutions that might play a role in that particular area of cooperation. The six areas are:

1. New materials
2. Energy storage systems
3. Solar energy
4. Advanced coal
5. Energy efficiency in small- and medium enterprises
6. Entrepreneurial activities in renewable energy technologies

New materials

The development of "New Materials" is a priority for the government of India. But from the information available on policies and institutions in our comparative frameworks (see main report), it seems that the Indian government does not currently support activities that are specifically designed to develop new materials with energy-related applications. In contrast, the United States has several national laboratories that support R&D activities on new materials with energy applications in mind. For example, the Ames Laboratory, Pacific Northwest National Laboratory, and Sandia National Laboratories all have programs on new materials for energy-related applications. There are several options for fostering collaboration:

- The Indian government could establish specific R&D grants for collaboration with Indian research institutes on new materials, or could create research centers which could then cooperate with U.S. institutions.
- The U.S. government could create a program to allow Indian researchers to access U.S. national labs active in materials development. This could provide U.S. institutions with more knowledge about what kind of materials, standards, and testing procedures are required in foreign markets.

Alternatively, U.S. organizations could operate with Indian institutions to establish research centers domestically, which would be open to both U.S. and Indian companies operating in the Indian market.

- The U.S. government could support the application of new materials in Indian demonstration projects. India currently has several large-scale demonstration projects, including fast-breeder reactors, supercritical boilers, and IGCC plants. Support for these demonstration projects could be in the form of procurement contracts for U.S. institutions and U.S. companies developing new materials for these demonstration projects.

U.S. policies and institutions	Indian policies and institutions
• Ames Laboratory • New Brunswick Laboratory • Pacific Northwest National Laboratory • Advanced Energy Research Project Grants (ARPA-E) • Advanced Research – New Frontiers in Power • Compressed/Liquid Hydrogen Tanks • Hydrogen Storage Engineering Center of Excellence • ITP Research & Development Program (cross-cutting) • Consortium for Research on Renewable Industrial Materials (CORRIM)	

TABLE A5.12. U.S. and Indian policies and institutions supporting innovation activities on new materials.

Energy storage systems

The development of energy storage systems for the transportation sector is a priority for both India and the United States. India has created a National Hydrogen Energy Roadmap and has instituted the Hydrogen Corpus Fund as a nodal agency for knowledge development, knowledge diffusion, and the creation of legitimacy (see Table A5.13). Simultaneously, India has several institutions (BHER and CPRI) and policies (particularly, rural development policies) that support R&D and the deployment of transmission, distribution, and storage technologies. However, India does not seem to be supporting demonstration projects in energy storage technologies for transportation or utility scale applications.

The United States, besides having a large number of institutions that support R&D and the deployment of transmission, distribution, and storage technologies (see our comparative frameworks in the main report) has a number of policies that are complementary to the Indian initiatives. For example, the U.S. government supports so-called "learning demonstrations" and has created consortia and partnerships that coordinate the demand and requirements for demonstration projects (see the comparative framework in the main report). Furthermore, the U.S. government has implemented several policies on hydrogen education.

Given the rural electrification challenge for India's government, and the legitimacy that the Indian government has established for hydrogen and fuel cell technologies in the transportation sector, the U.S. government might want to use its experience in developing "learning demonstrations" to develop similar programs in the Indian context. Such policies would provide the opportunity for U.S. companies to learn about their technologies, while it simultaneously might address some of the technical challenges that India faces in developing and extending their grids. Furthermore, these demonstration projects would allow Indian R&D institutions (like BHER and CPRI) to collaborate with U.S. counterparts in creating these demonstration projects.

U.S. policies and institutions	Indian policies and institutions
• Hydrogen and Fuel Cells Interagency Task Force	• National Hydrogen Energy Road Map
• Argonne National Laboratory	• Hydrogen Corpus Fund
• Lawrence Berkeley National Laboratory	• New Technology Group
• Lawrence Livermore National Laboratory	• Bharat Heavy Electrics Ltd. (R&D facilities)
• National Energy Technology Laboratory	• Central Power Research Institute
• Savannah River National Laboratory	• Rural Electricity Supply Technology (REST) Mission
• Gas Storage Technology Consortium	
• Compressed/Liquid Hydrogen Tanks	
• Hydrogen Storage Testing and Analysis	
• Hydrogen Storage Engineering Center of Excellence	
• H-prize	
• Energy Storage Program	
• Smart Grid Demonstration Projects	
• National Hydrogen Storage Project	
• Hydrogen Codes and Standards	
• Hydrogen Safety R&D Practices	
• Hydrogen and Fuel Cell Technology Validation	
• DOE National Hydrogen Learning Demonstration	
• Hydrogen Education Program	

TABLE A5.13. U.S. and Indian policies and institutions supporting innovation activities on energy storage systems.

Solar

Both India and the United States have assigned priority to the development of solar energy technologies. The Indian government has established ambitious targets and favorable manufacturing conditions for solar energy technology in their Jawaharlal Nehru National Solar Mission. It has also created the Solar Energy Centre to support R&D, and it is providing financial support for demonstration projects for both off-grid and MW-size on-grid solar energy plants.

The U.S. government also supports the development of solar energy technology, but its programs target slightly different elements. The U.S. programs include pre-incubator and incubator projects that support entrepreneurial activities on solar technology, funds for research or new test centers for the development, testing, and validation of new components, and the development of codes and standards and solar resource assessments.

The U.S. government could collaborate with the Indian government on developing test centers and creating capacity for solar resource assessments. The creation of research/test centers and of capacity to undertake solar resource assessment could bridge the gap between R&D-support and support for demonstration and deployment projects in India. Such collaborations would, in return, provide U.S. institutions and U.S. companies with valuable information about the opportunities for solar energy

U.S. policies and institutions	Indian policies and institutions
• Argonne National Laboratory • Brookhaven National Laboratory • Lawrence Berkeley National Laboratory • National Renewable Energy Laboratory • Savannah River National Laboratory • Solar Energy Technologies Program – including Solar Resource Assessment, Testing, Economic Modeling, and components • Photovoltaics Technology Pre-Incubator • Photovoltaics Technology Incubator • Photovoltaics Systems Development and Manufacturing • Technology Pathways Partnerships (TPPs) • Photovoltaics supply Chain and Cross-Cutting Technologies • National Laboratory Support of Solar Technology Development • Solar Energy Grid Integration Systems • Field Testing and Demonstration of Solar Systems • Solar America Board for Codes and Standards	• Solar Energy Centre • Jawaharlal Nehru National Solar Mission • Research, Design and Development of Solar Thermal Technologies • Promotion of Grid Interactive Power Generation Projects • Solar Power Generation Based Incentive • Grid Connected Solar PV Power Generation • Demonstration and Promotion of Solar PV devices in urban areas & industry • SWES – Program on Small Wind energy and Hybrid Systems

TABLE A5.14. U.S. and Indian policies and institutions supporting innovation activities on solar energy.

in India and about the particular challenges that Indian companies face in developing these technologies. Furthermore, such collaboration would provide valuable information for those U.S. small- and medium-sized businesses with entrepreneurial ambitions in India.

Advanced Coal

The development and deployment of more efficient coal technologies is a fourth area for possible international cooperation. Although the United States' national priority is carbon capture and storage technologies (CCS), there are sufficient U.S. national policies supporting advanced coal technologies that collaboration with India can complement existing activities. India, on the other hand, has placed less priority on CCS technologies and more on advanced coal technologies. India is supporting the development of two IGCC demonstration plants and the deployment of new supercritical boilers. Furthermore, the Indian government is commissioning private-public partnerships to develop 400 MW power projects.

The United States has a large number of R&D programs for fossil energy (advanced turbines, coal utilization science, computational energy science, and high performance materials), but except for FutureGen and regional partnerships on carbon capture, no large-scale demonstration projects.

Collaborative demonstration projects on advanced coal could benefit both U.S. and Indian companies. These demonstration projects could be organized in two ways. Collaborative demonstration projects could be developed jointly with procurement contracts for U.S. research institutes and companies as part of U.S. contribution and procurements contracts for Indian companies as part of India's contribution. Alternatively, the U.S. government and the Indian government could support demonstration projects on their own soil with mechanisms for coordination and shared learning.

U.S. policies and institutions	Indian policies and institutions
• National Energy Technology Laboratory • Oak Ridge National Laboratory • Clean Coal Power Initiative • FutureGen (2.0) • Innovation for Existing Power Plants (IEP) Program • Power Systems Development Facility • Turbines of Tomorrow • Advanced Research – New Frontiers in Power • Other Low-Carbon Fuel Alternatives from Coal	• Standing Scientific Research Committee of the Ministry of Coal • Bharat Heavy Electricals Ltd. (R&D facility) • Commissioning of supercritical coal-fired power stations • IGCC demonstration plant • Deployment of 800 MW supercritical boilers • Ultra Mega Power Projects

TABLE A5.15. U.S. and Indian policies and institutions supporting innovation activities on advanced coal.

U.S. policies and institutions	Indian policies and institutions
• Advanced Energy Research Project Grants (ARPA-E)	• Energy Conservation Act
• Industrial Assessment Centers	• Bureau of Energy Efficiency
• Small Business Innovation Research	• Indian Renewable Energy Development Agency Ltd.
• Small Business Technology Transfer Program	• National Campaign on Energy Conservation
• Clean Energy Application Centers	• Energy Conservation for Tea Production
• Small Business Awards	
• Best Practices Program	
• Save Energy Now – LEADER organizations	
• Save Energy Now – ALLY organizations	
• Integrated Environmental Strategies program (from EPA)	

TABLE A5.16. U.S. and Indian policies and institutions supporting innovation activities in energy efficiency for small- and medium enterprises.

Energy efficiency in small- and medium-sized enterprises

The comparative frameworks indicated that India, in comparison to the United States, appears to have no programs that promote entrepreneurial activities in energy efficiency and only limited programs that support knowledge development and diffusion of energy-efficient technologies. The United States, on the other hand, has several programs that specifically target entrepreneurial activities in small enterprises and the energy–intensive industry. Finally, both the U.S. government and the Indian government spend much more effort on developing deployment policies that raise the demand for energy efficient appliances and processes than deployment policies that support the developers of energy efficient appliances.

A United States-India collaboration could provide entrepreneurial U.S. companies with access to new markets, while it could provide India with the much needed support linking their national R&D programs to their national deployment programs. Furthermore, it could provide U.S. firms with experience in getting to know new markets for their technologies, while Indian companies could acquire access to novel energy efficient practices. Such collaboration would also provide a "knowledge diffusion" function in that U.S. and Indian companies and research institutions could learn from each other's problems.

Entrepreneurial activities in renewable energy technologies

A comparison of the comparative frameworks in our main report indicated that the U.S. government and the Indian government have a similar number of policies in place for promoting renewable energy technologies. Both governments have many policies to create knowledge, to provide resources, to provide guidance of search, to create legitimacy, and to create markets for renewable energy technologies. Knowledge diffusion and entrepreneurial activities receive less policy support in comparison to any of the other innovation functions. In the United States, the support that does exist for entrepreneurial activities is primarily for solar energy. A comparison with the support for energy efficiency technologies indicates that there are far less local information centers, less technology transfer support, and fewer local partnerships than for solar energy. In India, the support for entrepreneurial activities for renewable energy technologies mainly targets local entrepreneurs installing and developing solar water heaters.

Since both the U.S. government and the Indian government have similar gaps in their energy technology innovation policies in the area of knowledge diffusion and entrepreneurial activities for renewable energy technologies, there is an opportunity for collaboration. For example, the U.S. and Indian governments could provide support for entrepreneurs that work in both countries, bring entrepreneurs together during workshops and conferences, or provide a platform where local governments can share experiences or their need for new technologies. A particular interesting area of cooperation for entrepreneurial activities is the development of technologies for local biomass as an energy source.

U.S. policies and institutions	Indian policies and institutions
• Photovoltaics Technology Pre-Incubator Photovoltaics Technology Incubator • Small Business Innovation Research • Small Business Technology Transfer Program • Clean Energy Application Centers • Small Business Awards • Federal Wind Siting Information Centers	• Biogas based Distributed/Grid power Generation Programme • Rural Electricity Supply Technology (REST) Mission • Accelerated development and deployment of SWH systems in domestic, industrial and commercial sectors • National Biofuel Centre, PCRA • Indian Renewable Energy Development Agency Limited

TABLE A5.17. U.S. and Indian policies and institutions supporting entrepreneurial activities on renewable energy technologies.

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