Representing Technology and Technological Change in IAMs

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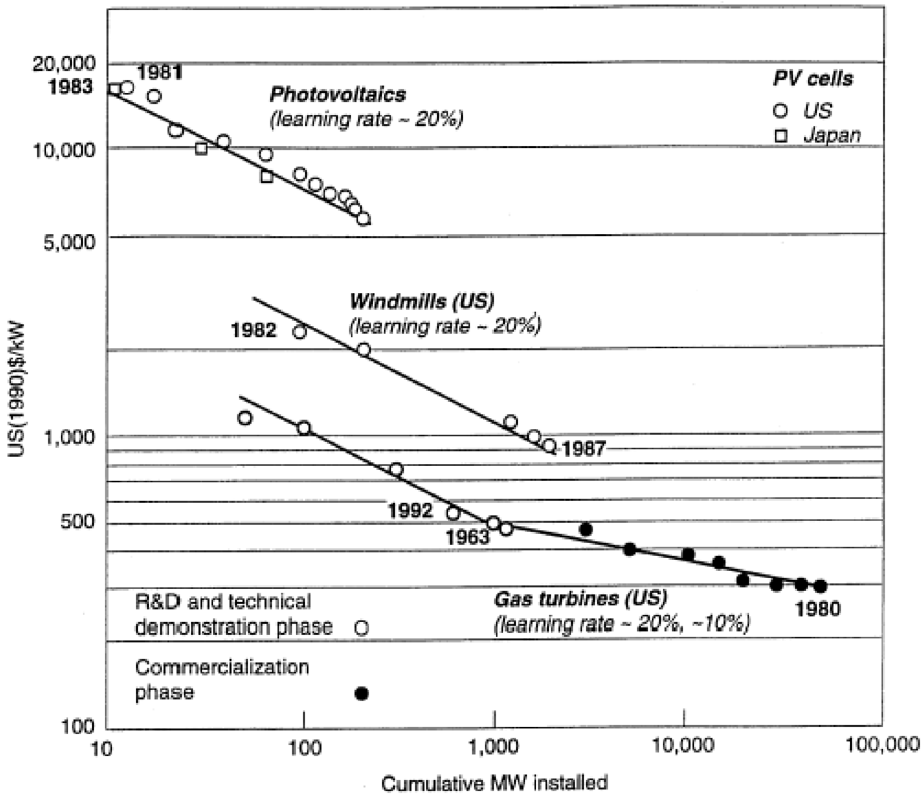
Snowmass

Office of Science
U.S. Department of Energy
Pacific Northwest National Laboratory

What are the top priorities for better representing tech change in IAMs?

- The processes of technological change?
  - Induced R&D, learning processes, economies of scale, spillovers
  - The transition to N^{th} of a kind technology
- Regional variations in technology and the uptake of technology?
- Diffusion market failures (e.g., energy efficiency gap)?
- “Other” obstacles to deployment?
  - Nuclear waste, safety, security
  - CCS infrastructure and implementation issues
  - Bioenergy interactions with agricultural policy and food security
- The “realism” of technology representations and assumptions?
  - Wind supplies, distribution system and intermittency
  - Energy end use technology representations
- Potential limitations on inputs?
- Interactions between technologies, and between technologies and other systems?
  - Hydrogen & CCS
  - Renewables, transportation, storage, and distribution
  - Dedicated energy crops and other uses of land

How have modelers captured the process of technological change in IAMs?



Source: Grubler, et al. (1999)

Traditionally, models have taken technological change as an input (**Exogenous**).

A number of models have allowed technological change to respond to model variables, and therefore to be induced by policies (**Endogenous**).

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What questions have been explored in IAMs with endogenous technological change?

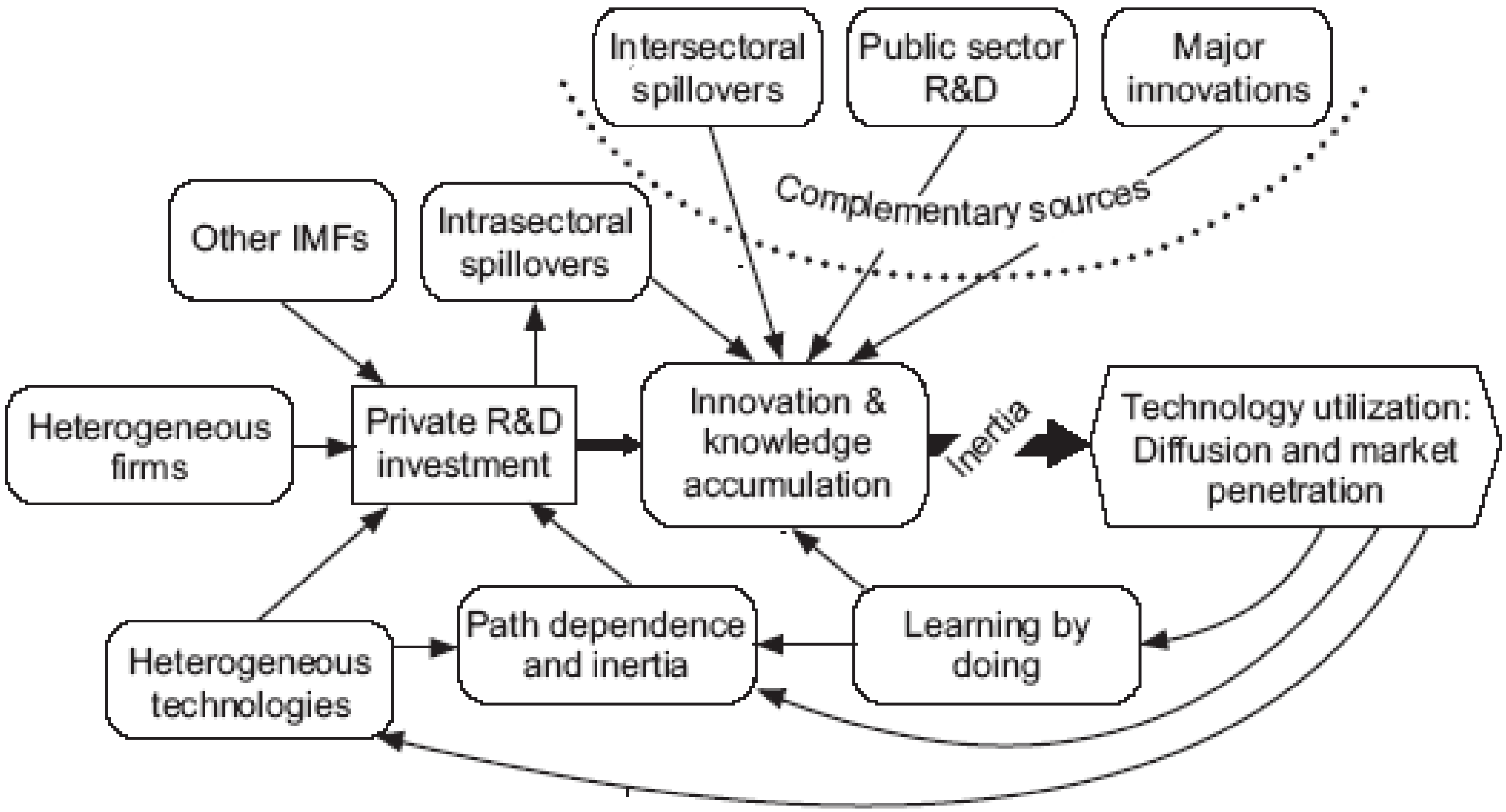
- Optimal emissions trajectories with a focus on near-term action.
- Optimal policy portfolio: mix of technology and emissions instruments.
- The costs of emissions mitigation.
- The possible character and implications of path dependence.

Analyses have largely been exploratory.

Endogenous technological change has not become part of the standard toolkit of IAM modelers.

Experience curves are the most common method of endogenizing technological change in IAMs.

Why hasn't endogenous technological change become a mainstream part of IAMs?



Source: Clarke and Weyant. 2002. "Modeling Induced Technological Change – An Overview," RFF

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How might a IAM modeler think about representing technological change?

A SAMPLING OF ISSUES

Interactions spillovers and own-industry activities

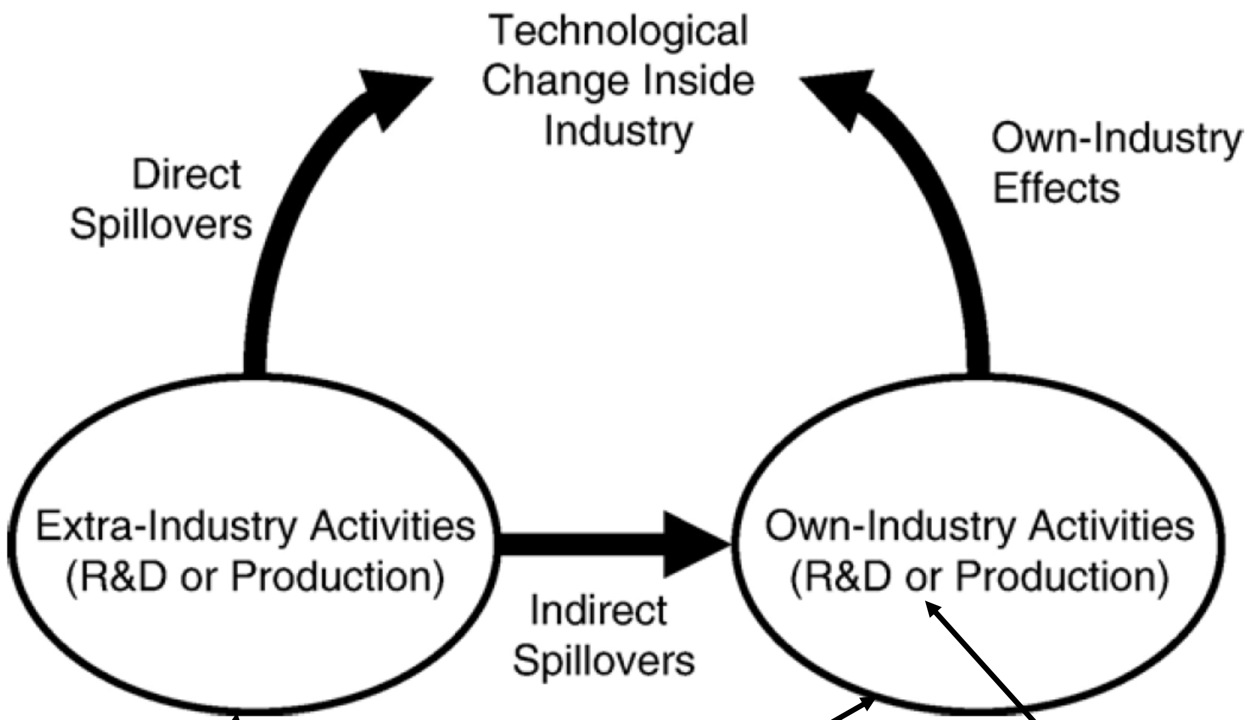
Interindustry, intraindustry, international spillovers

Interactions: R&D and production effects

Different colors of R&D: basic vs. applied; public vs. private

Interactions: basic and applied R&D

Specifying spillovers terms, productivity of R&D, progress ratios



To possible locations for activities driving technological change

Two possible drivers of tech change: R&D and/or production

The literature on technological change indicates that spillovers are pervasive

			Rate of return to:		
Study	**Country**	**Time Period**	**Industry**	**Firms in Other Industries**	**National**
Bernstein & Nadiri (1988)*	USA	1958 to 1981	19 to 37	2 to 145	21 to 172
Bernstein & Nadiri (1991)*	USA	1957 to 1986	25 to 39 (32)	0 to 113 (24)	28 to 142 (55)
Goto & Suzuki (1989)	Japan	1978 to 1983	26	80	106
Griliches & Lichtenberg (1984)	USA	1959 to 1978	11 to 31 (24)	69 to 90 (80)	41 to 62 (55)
Scherer (1982)	USA	1948 to 1978	19 to 43	64 to 147	103
Scherer (1984)	USA	1973 to 1978	29	74 to 104	103
Sveikauskas (1981)	USA	1959 to 1969	7 to 25	50	57 to 75
Terleckyj (1974)	USA	1948 to 1966	12 to 37 (26)	45 to 187 (92)	73 to 107 (90)
Terleckyj (1980)	USA	1948 to 1966	25 to 27 (26)	82 to 183 (108)	107 to 110 (108)
Wolff & Nadiri (1987)	USA	1947 to 1972	11 to 19 (15)	10 to 90 (50)	21 to 109 (65)
Bernstein (1989)*	Canada	1963 to 1983	34 to 57 (42)	0 to 70 (26)	39 to 104 (68)
Hanel (1988)	Canada	1971 to 1982	50	100	150
Mohnen & Lepine (1991)	Canada	1975 to 1983	15 to 285 (67)	2 to 90 (29)	21 to 329 (45)
Sterlacchini (1989)	UK	1954 to 1984	2 to 33 (16)	7 to 32 (15)	18 to 56 (45)

Note: Numbers in parentheses represent unweighted arithmetic means

** Net rate of return converted to a gross rate of return assuming a depreciation rate of 10 percent.*

From Australian Industry Commission (1995). *Research and Development*. Australian Government Publishing Service.

"In spite of these difficulties, there has been a significant number of reasonably well done studies all pointing in the same direction: R&D spillovers are present, their magnitude may be quite large, and social rates of return remain significantly above private rates." (Griliches, 1992, p. S43)

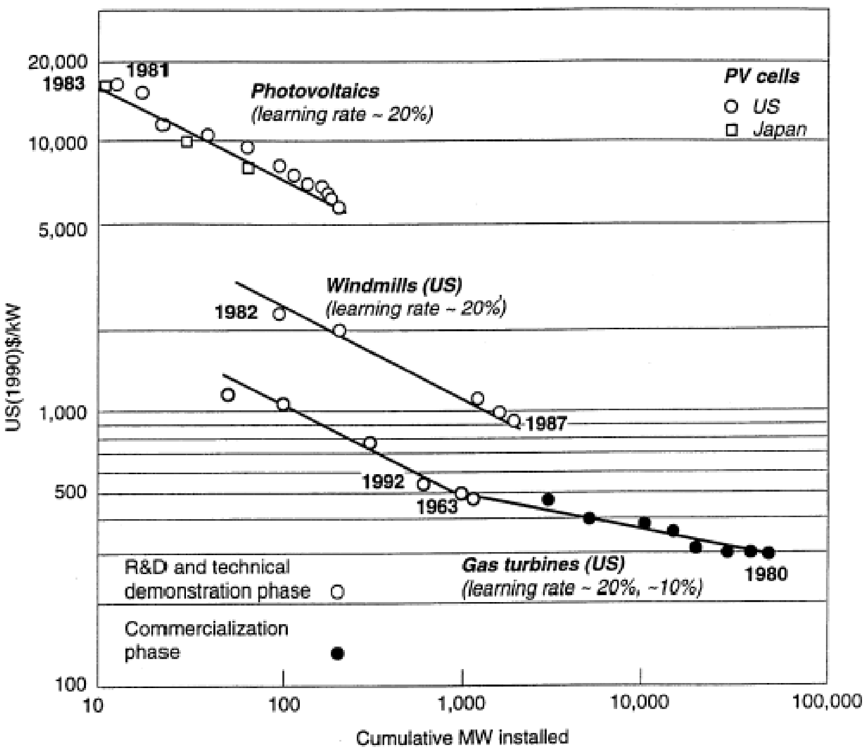
The literature on technological change indicates that spillovers are often indirect

Source of opportunity	High opportunity sectors			Low opportunity sectors		
	electronic components	aircraft and missiles	drugs	stone, clay and glass	metal products	non-electrical machinery
Basic and applied sciences						
Biology	1.8	1.2	6.8	1.4	1.3	1.4
Chemistry	6.0	3.8	6.6	5.8	4.6	3.5
Physics	6.5	5.6	3.3	4.2	4.6	4.5
Computer science	6.2	6.3	5.1	4.4	4.7	3.8
Material science	6.6	6.4	3.1	5.7	6.0	4.9
External contributions						
Material suppliers	5.1	5.1	3.2	3.9	4.7	4.3
Equipment suppliers	5.8	5.1	3.7	4.4	5.1	4.5
Users	4.9	4.9	4.2	3.5	4.4	4.6
University research	4.0	3.1	5.4	2.7	2.7	2.8
Government laboratories	3.6	4.1	4.8	2.1	2.3	2.5
Natural trajectories						
Mechanization/Automation	5.1	5.1	4.0	5.1	5.0	4.9
Improving process yield	6.4	5.0	5.5	5.1	4.8	4.5
Improving input materials	5.4	5.4	4.5	4.6	4.7	4.4
Changes in product dimensions	6.1	3.7	3.4	3.3	3.6	3.7
Improving product performance	6.5	6.2	5.1	5.2	5.1	5.8
Designing for market segments	5.3	5.7	3.3	4.4	4.4	5.1

From Klevorick, A., R. Levin, R. Nelson, and S. Winter (1995). On the sources and significance of interindustry differences in technological opportunities. *Research Policy* 24, 185-205.

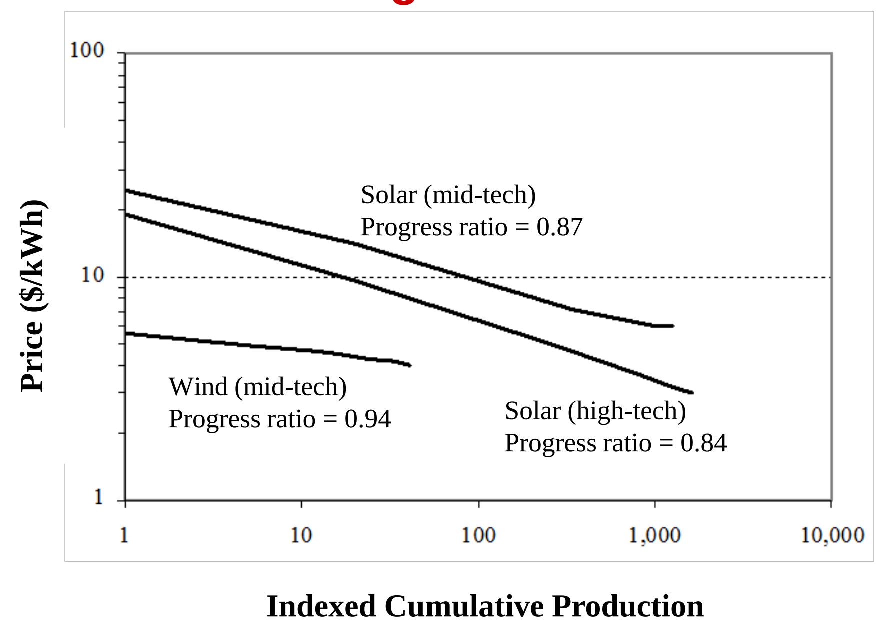
Experience curves are valuable but should be approached with caution

Empirical experience curves



Source: Grubler, et al. (1999)

Model Results: Exogenous Technological Advance



"the problem of omitted variable bias needs to be taken seriously"

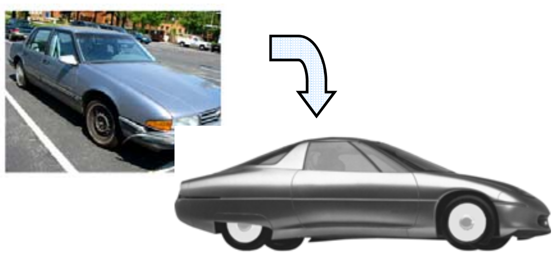
Soderholm, P., Sundqvist, T., 2003. Learning curve analysis for energy technologies: theoretical and econometric issues. Paper presented at the Annual Meeting of the International EnergyWorkshop (IEW), June 2003 in Laxenburg, Austria.

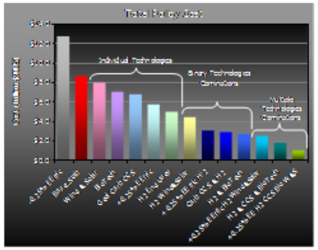
How are IAMs used to inform technology-related decision making?

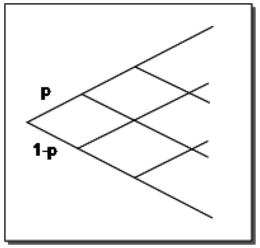
How can we better inform R&D strategy:

(1) how much effort is appropriate?

(2) how should it be allocated?







ISSUES	Potential for Advance, R&D Impact on Advance	Value & Implications of Technology	R&D Allocation Under Uncertainty
TOOLS	Technology Assessments Historical Analysis	Integrated Assessment Models	Portfolio Models, Decision Analysis

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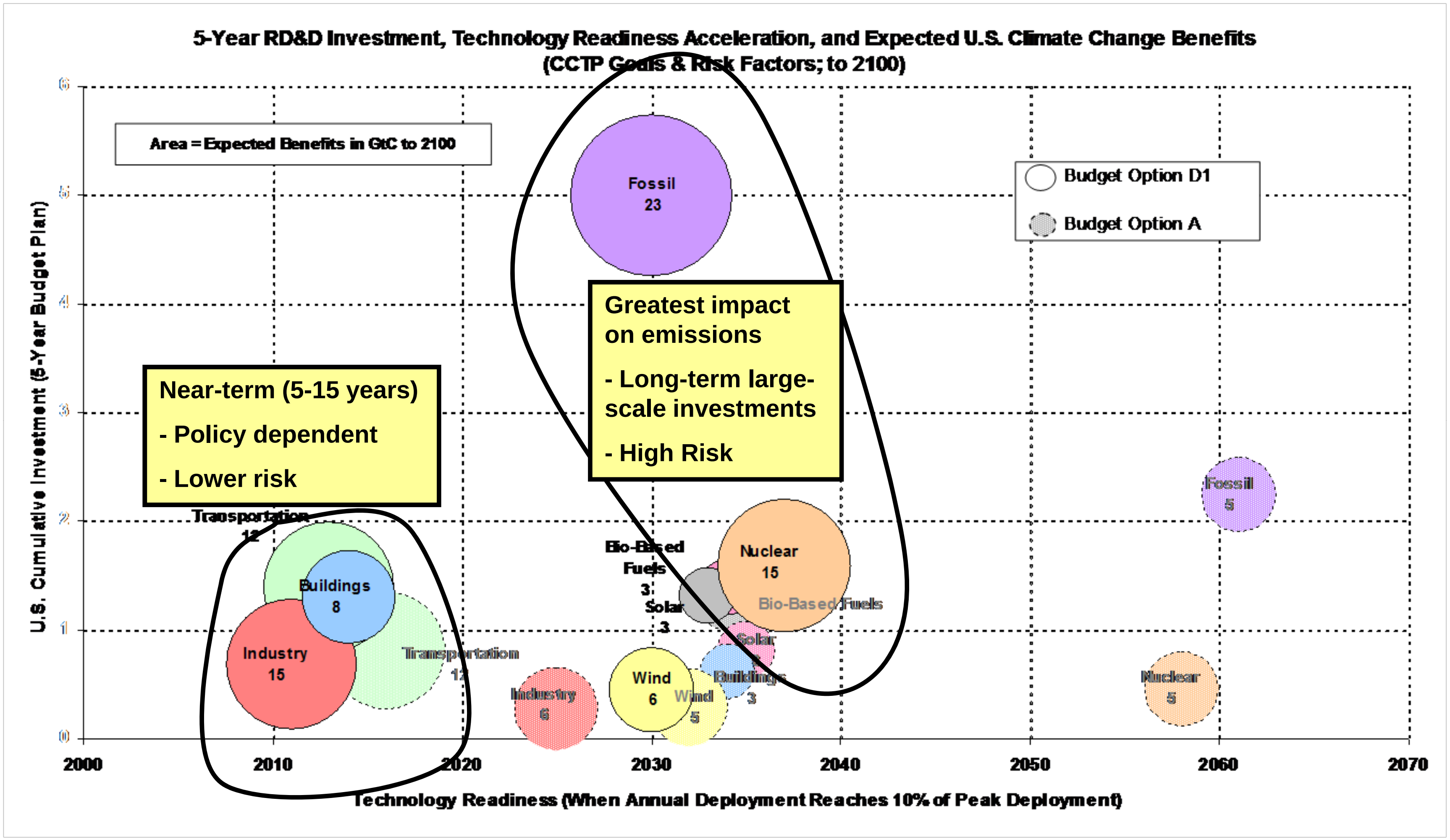
Starting Point: Detailed Portfolio Assessments

(note: this is old data from last year's template)

CCTP Strategic Goal	Key Element of Strategy		CCTP Strategic Plan -- Corresponding Technologies in Scenarios Analysis	Lead	Most Challenging Technical Scenario	Units	Scenarios Years & Quantities -- U.S. Only					Likelihood of CCTP Goal Attainment*				
							2020	2030	2040	2050	2100	Very Unlikely	Unlikely	Maybe	Likely	Very Likely
1 Reducing Emissions from Energy End-Use and Infrastructure	1.1	Transportation	Primary Energy Reduction	EE	BSS 450	GtC/yr	0.10	0.14	0.19	0.23	0.34					
	1.2	Buildings	Primary Energy Reduction	EE	BSS 450	GtC/yr	0.04	0.08	0.11	0.14	0.15					
	1.3	Industry	Primary Energy Reduction	EE	BSS 450	GtC/yr	0.12	0.17	0.21	0.24	0.18					
	1.4	Electric Grid and Infrastructure	Enabling Technology, U.S. Grid Demand	OE	NEB 450	Trillion kWh/yr	6.67	7.35	7.92	8.38	9.49					
2 Reducing Emissions from Energy Supply	2.1	Low-Emission, Fossil-Based Fuels and Power	Electricity: Coal w/CCS	FE	CLC 450	GtC/yr	0.02	0.05	0.11	0.19	0.33					
			Electricity: Natural Gas w/CCS	FE	CLC 450	GtC/yr	0.02	0.04	0.08	0.15	0.26					
	2.2	Hydrogen	Hydrogen Production	EE	CLC 450	Quads	2.40	3.10	4.00	5.10	7.40					
	2.3	Renewable Energy and Fuels	Electricity: Solar Power	EE	NEB 450	GtC/yr	0.00	0.00	0.02	0.04	0.06					
			Electricity: Wind Power	EE	NEB 450	GtC/yr	0.00	0.02	0.06	0.11	0.13					
			Bio-Based Fuels	EE	BSS 450	GtC/yr	0.00	0.00	0.02	0.05	0.06					
	2.4	Nuclear Fission	Electricity: Gen III Reactors	NE	NEB 450	GtC/yr	0.01	0.05	0.13	0.24	0.37					
			Electricity: Gen IV Reactors	NE	NEB 450	GtC/yr	0.00	0.00	0.02	0.06	0.15					
			Electricity: International Tech. --GNEP	NE	NEB 450-W	Trillion kWh/yr	0.01	0.01	0.02	21.94	39.06					
	2.5	Fusion Energy	Electricity: Fusion Energy, Others	SC	BSS 450	GtC/yr	0.00	0.00	0.01	0.04	0.35					
3 Capturing and Sequestering Carbon Dioxide	3.1	Carbon Capture	(Embedded in 2.1)	FE	N/A	N/A	TBD									
	3.2	Geological Storage	Carbon Storage	FE	CLC 450	GtC/yr	0.04	0.09	0.20	0.35	0.61					
	3.3	Terrestrial Sequestration	TBD	USDA	TBD	GtC/yr	TBD									
	3.4	Ocean Sequestration	Not Applicable This Round	DOE	N/A	N/A	TBD									
4 Reducing Emissions of Non-CO_2 Greenhouse Gasses	4.1	Methane Emissions from Energy and Waste	CH_4 in CO_2-Equivalence	DOE/EPA	CLC 450	GtC-Eq./yr	TBD									
	4.2	Methane and Nitrous Oxide Emissions from Agriculture	TBD--CH_4 (Part)	USDA	CLC 450	GtC-Eq./yr	TBD									
			TBD--N_2O (Part)	USDA	CLC 450	GtC-Eq./yr	TBD									
	4.3	Emissions of High Global-Warming Potential Gases	Short-Lived F-Gases in CO_2-Equivalence	EPA	CLC 450	GtC-Eq./yr	TBD									
			Long-Lived F-Gases in CO_2-Equivalence	EPA	CLC 450	GtC-Eq./yr	TBD									
	4.4	Nitrous Oxide Emissions from Combustion and Industrial Sources	N_2O in CO_2-Equivalence	EPA	CLC 450	GtC-Eq./yr	TBD									
	4.5	Emissions of Tropospheric Ozone Precursors and Black Carbon	TBD	EPA	TBD	GtC-Eq./yr	TBD									
5 Enhancing Capabilities to Measure and Monitor Greenhouse Gasses	5.2	MM -- Energy Production and Efficiency	N/A	DOE			Refer to Strategic Plan, Chapter 8									
	5.3	MM -- CO_2 Capture and Sequestration	N/A	DOE			Refer to Strategic Plan, Chapter 8									
	5.4	MM -- Other Greenhouse Gases	N/A	EPA			Refer to Strategic Plan, Chapter 8									
	5.5	MM -- Integrated Systems Architecture	N/A	SC			Refer to Strategic Plan, Chapter 8									
6 Bolster Basic Science Contributions to Technology Development	6.1	Strategic Research	N/A	SC			Refer to Strategic Plan, Chapter 9									
	6.2	Fundamental Science	N/A	SC			Refer to Strategic Plan, Chapter 9									
	6.3	Exploratory Research	N/A	SC			Refer to Strategic Plan, Chapter 9									

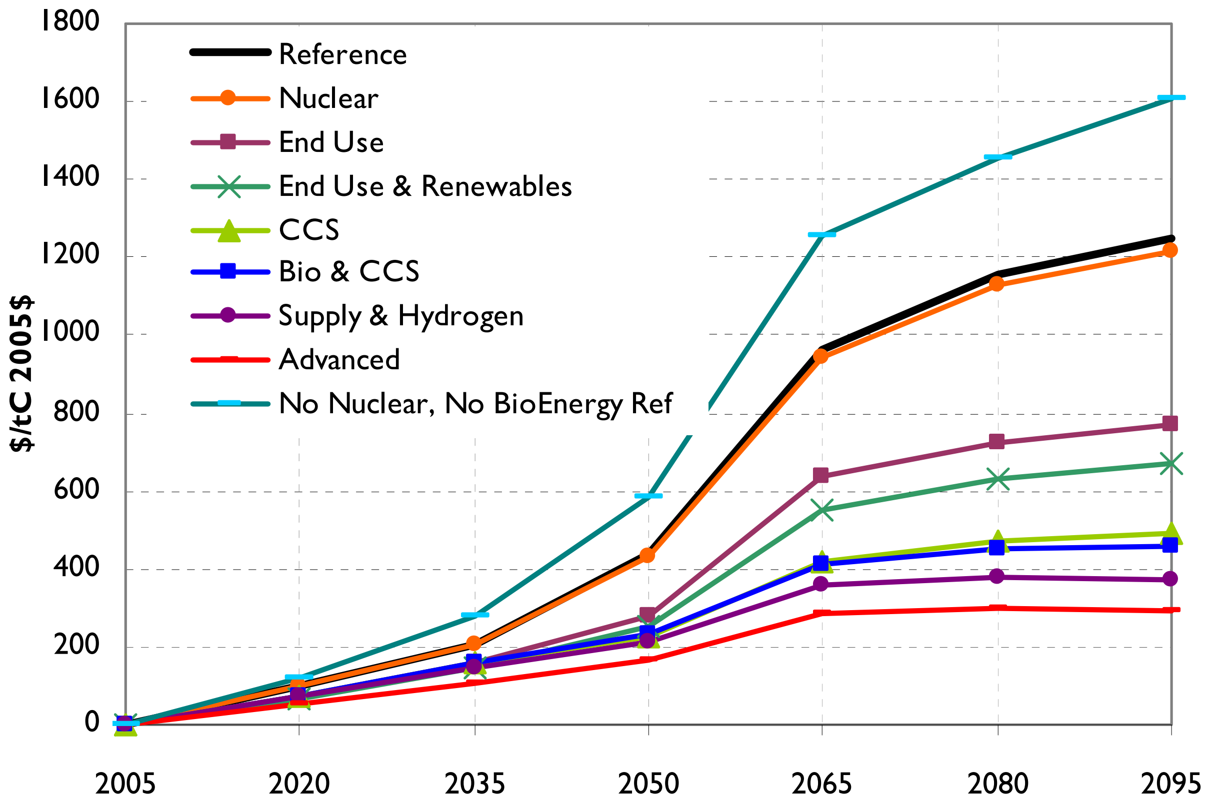
* In view of various hypothetical RD&D portfolios and other factors. Key: Very Likely (90-100%); Likely (60-90%); Maybe (40-60%); Unlikely (10-40%); Very Unlikely (0-10%)

Focus U.S. Federal RD&D Investment on High Return Areas



Ongoing CCTP Scenarios: A Richer Set of Evolutionary Technology Pathways

Carbon Price (450 ppmv) under a Technology Pathways



IAMs provide information on the value of technology for addressing climate change.

Draft results: subject to change

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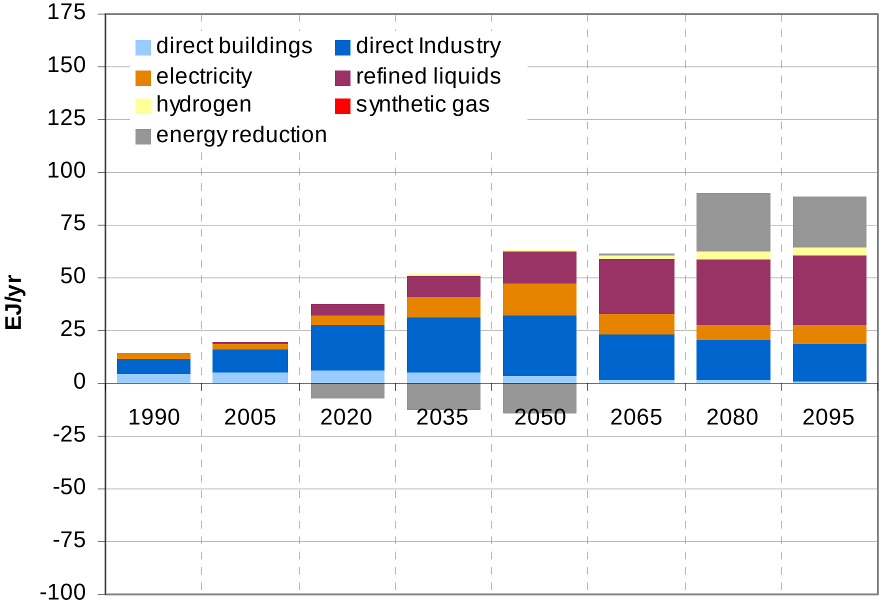
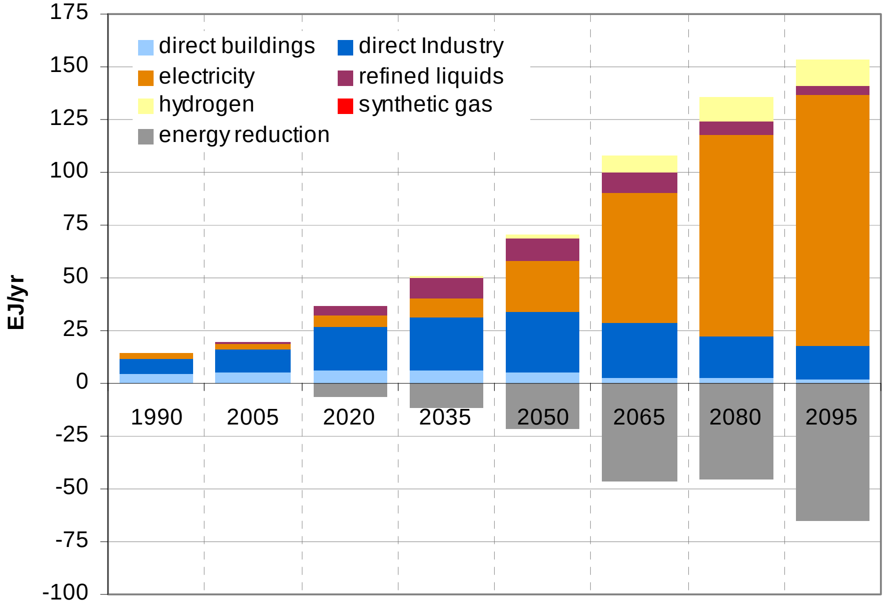
The interactions between bioenergy, CCS, and terrestrial carbon

Global Biomass Consumption: No CCS (450 ppmv)



Global Biomass Consumption: w/CCS (450 ppmv)



Bioenergy crops are increasingly used in liquid fuel applications,

& the value of carbon in land holds back bioenergy consumption

Bioenergy crops are primarily used in electricity applications with CCS,

& there is a large expansion of bioenergy consumption.

The interactions between bioenergy, CCS, and terrestrial carbon

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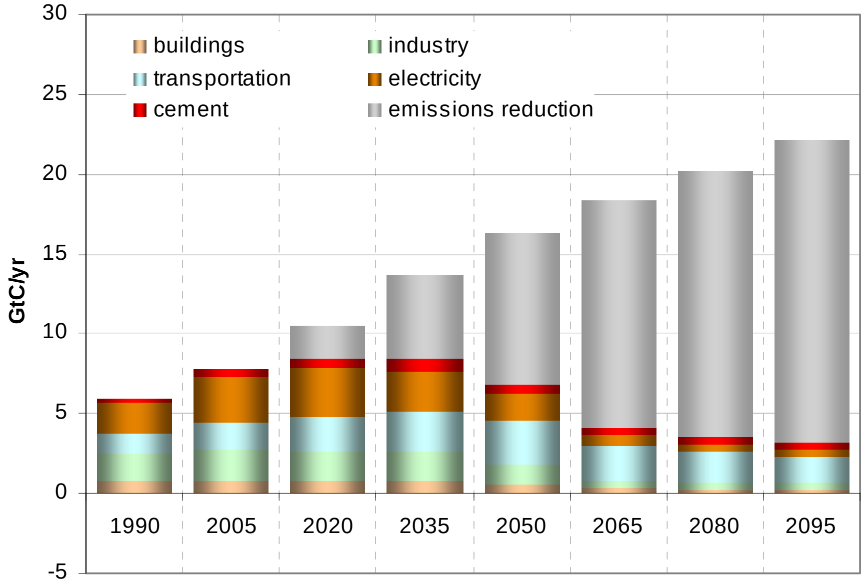

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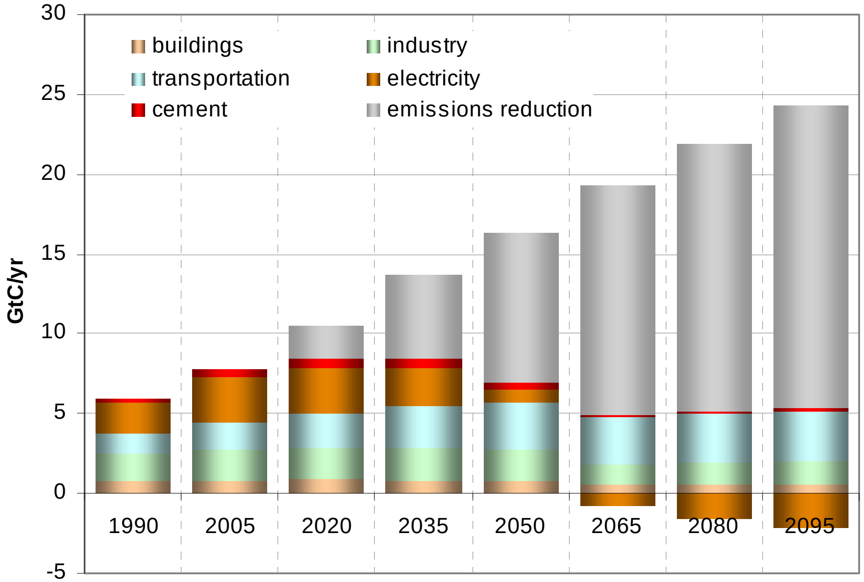

Bio with CCS allows for negative emissions from electricity in the future

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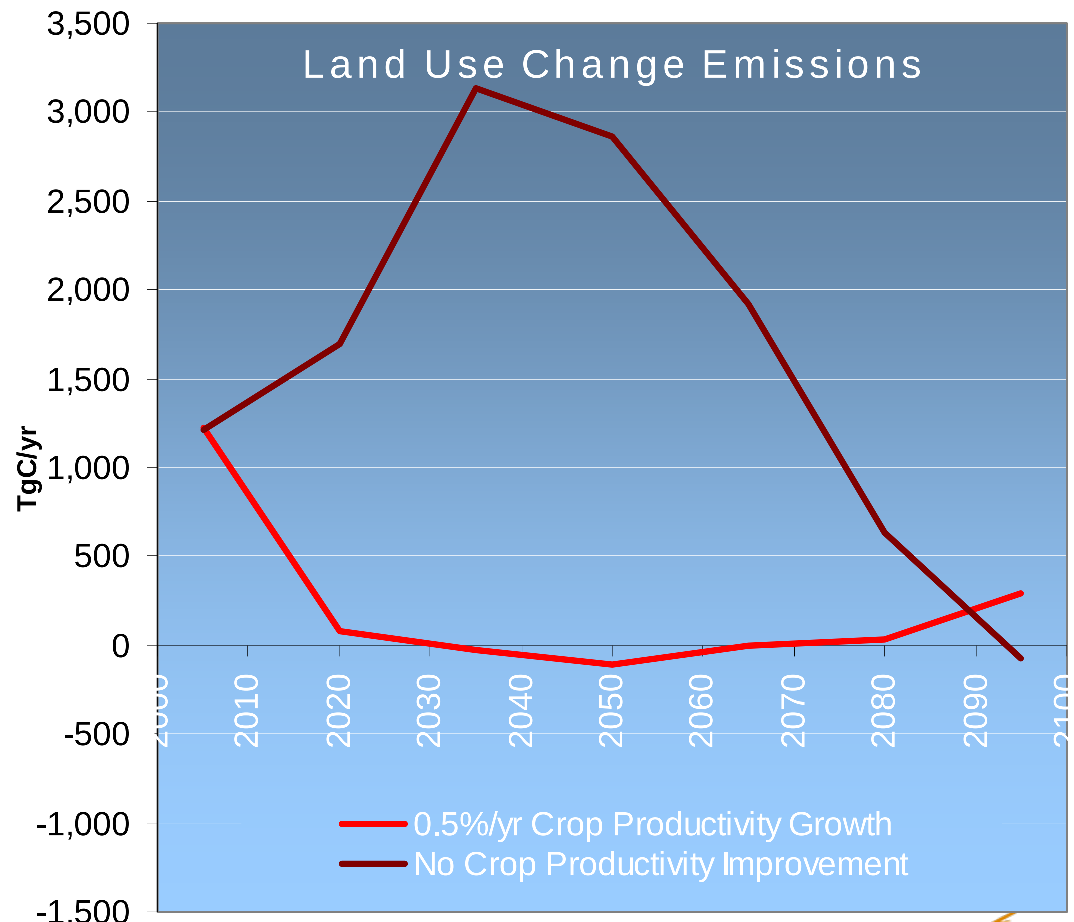
The Role of Technological Advances in Agriculture

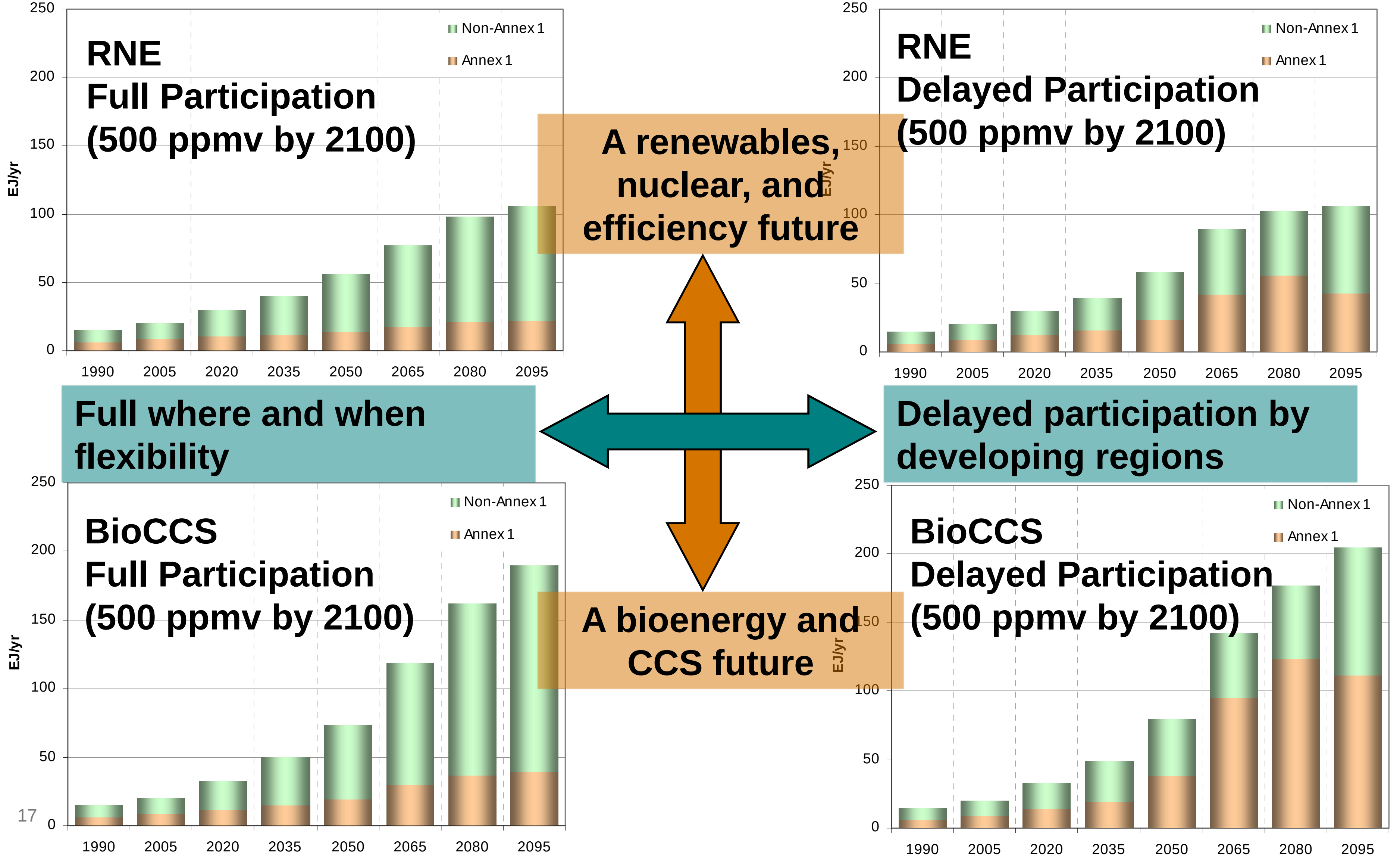
Cumulative Emissions 2005 to 2095 (no carbon policy)

- 0.5%/yr crop productivity growth:
  - 11 PgC
- No crop productivity growth:
  - 162 PgC



IAMs can provide insights into the roles of technologies that are not always considered as part of the climate technology portfolio

Global biomass consumption under differing technology and international policy assumptions



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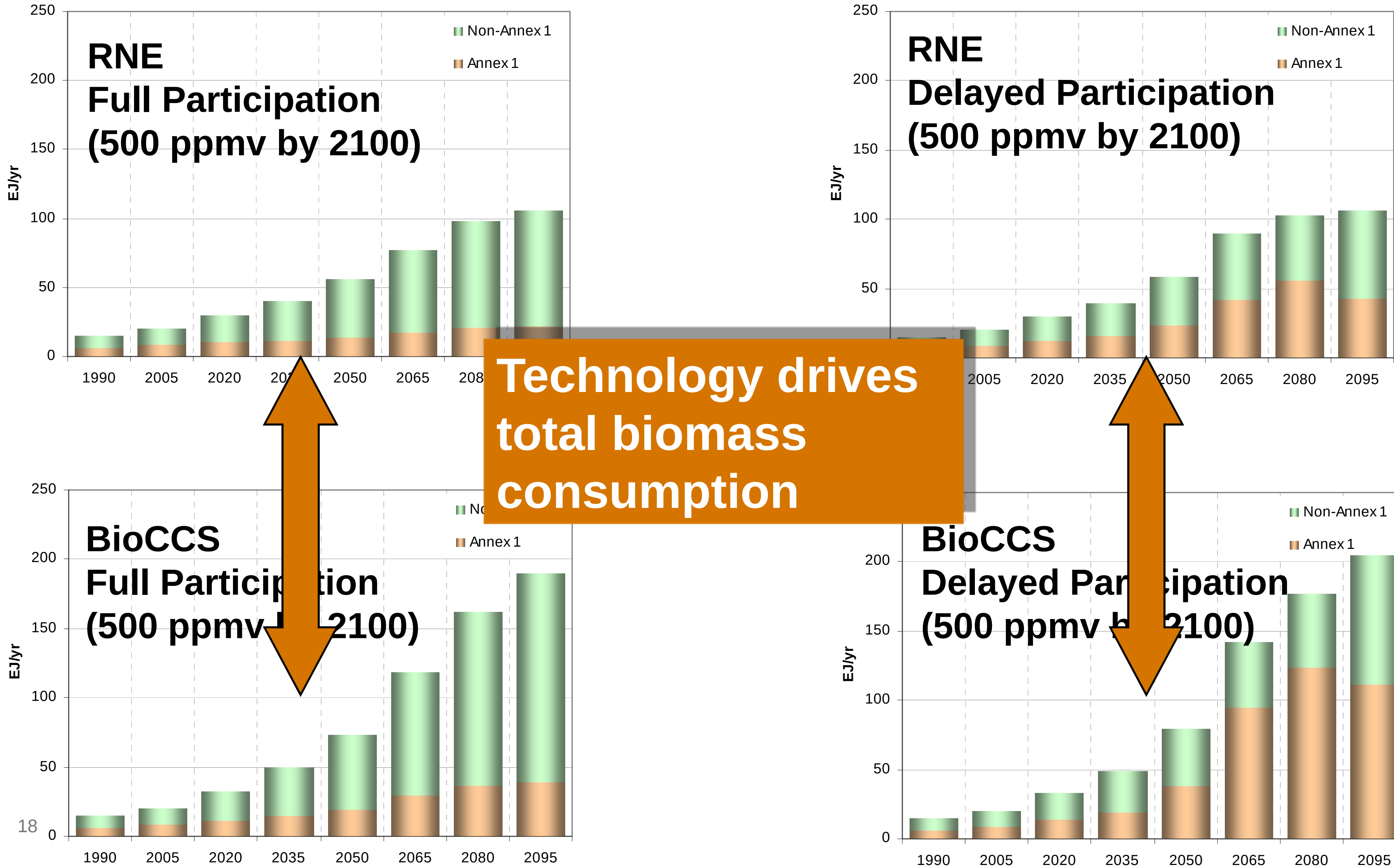

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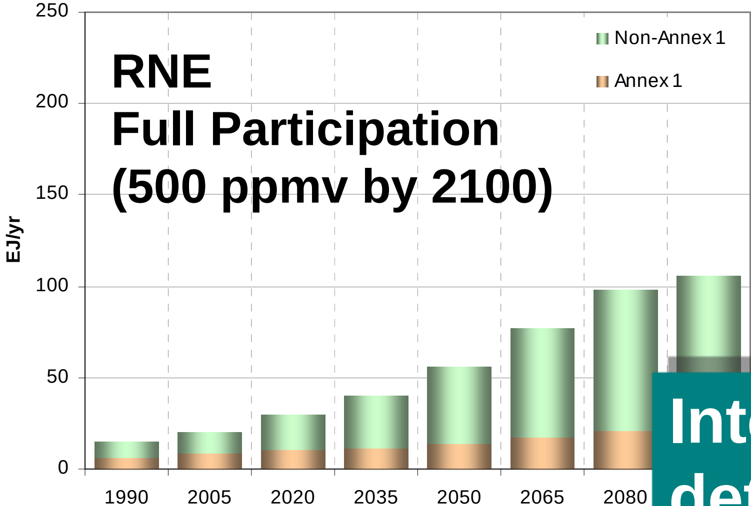
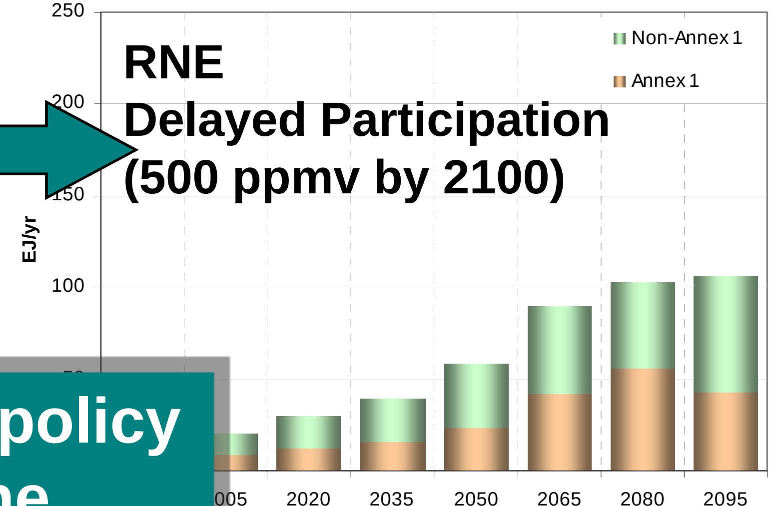
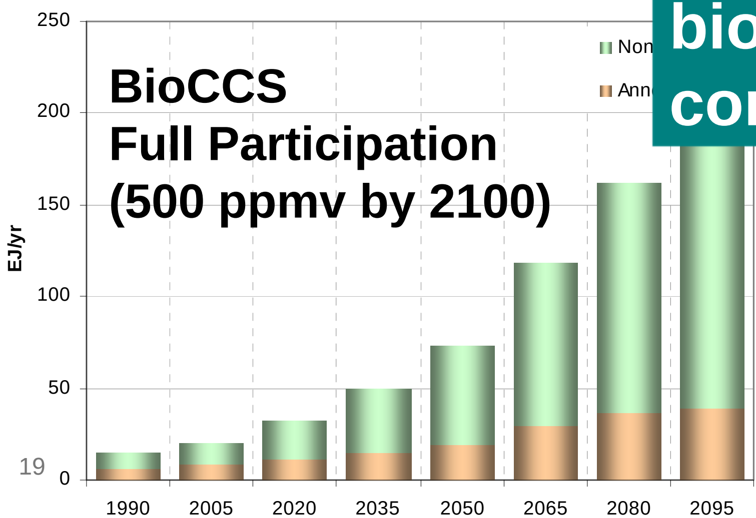
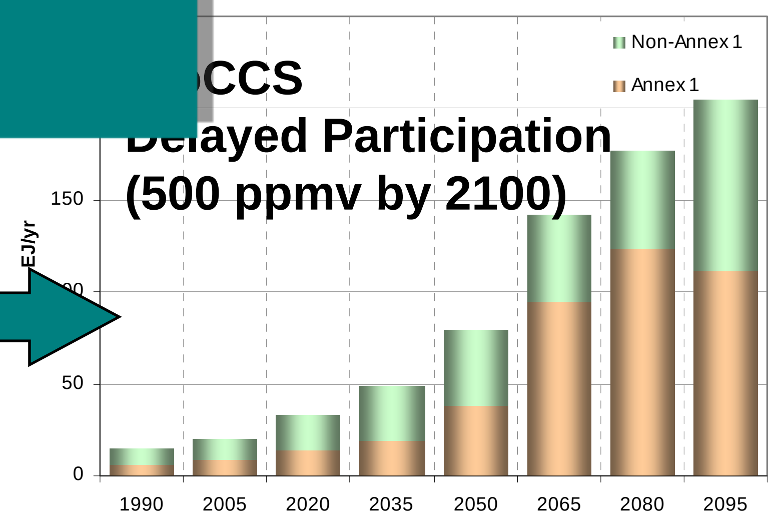




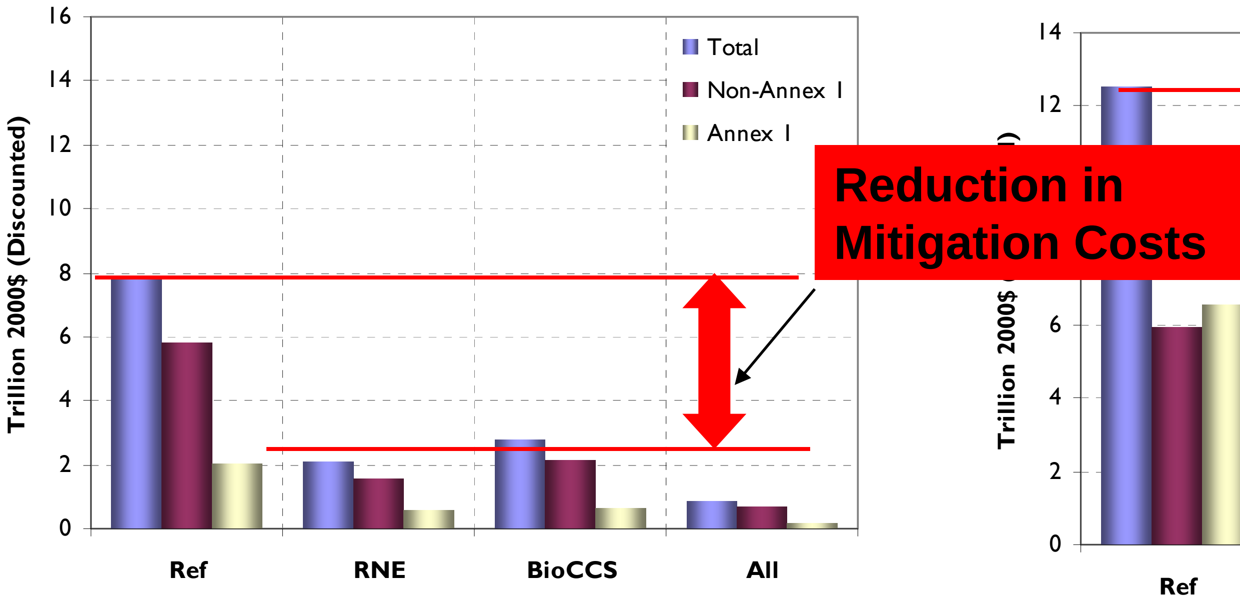
International policy determines the distribution of biomass consumption



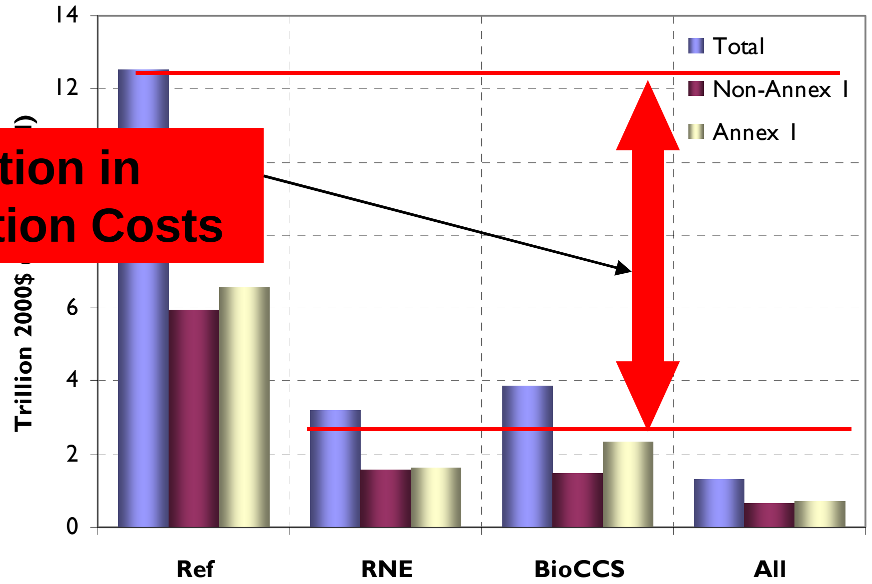


Technology is even more important in an imperfect world

Total Discounted Cost of Mitigation, 2005 through 2095



Full Participation



Delayed Participation

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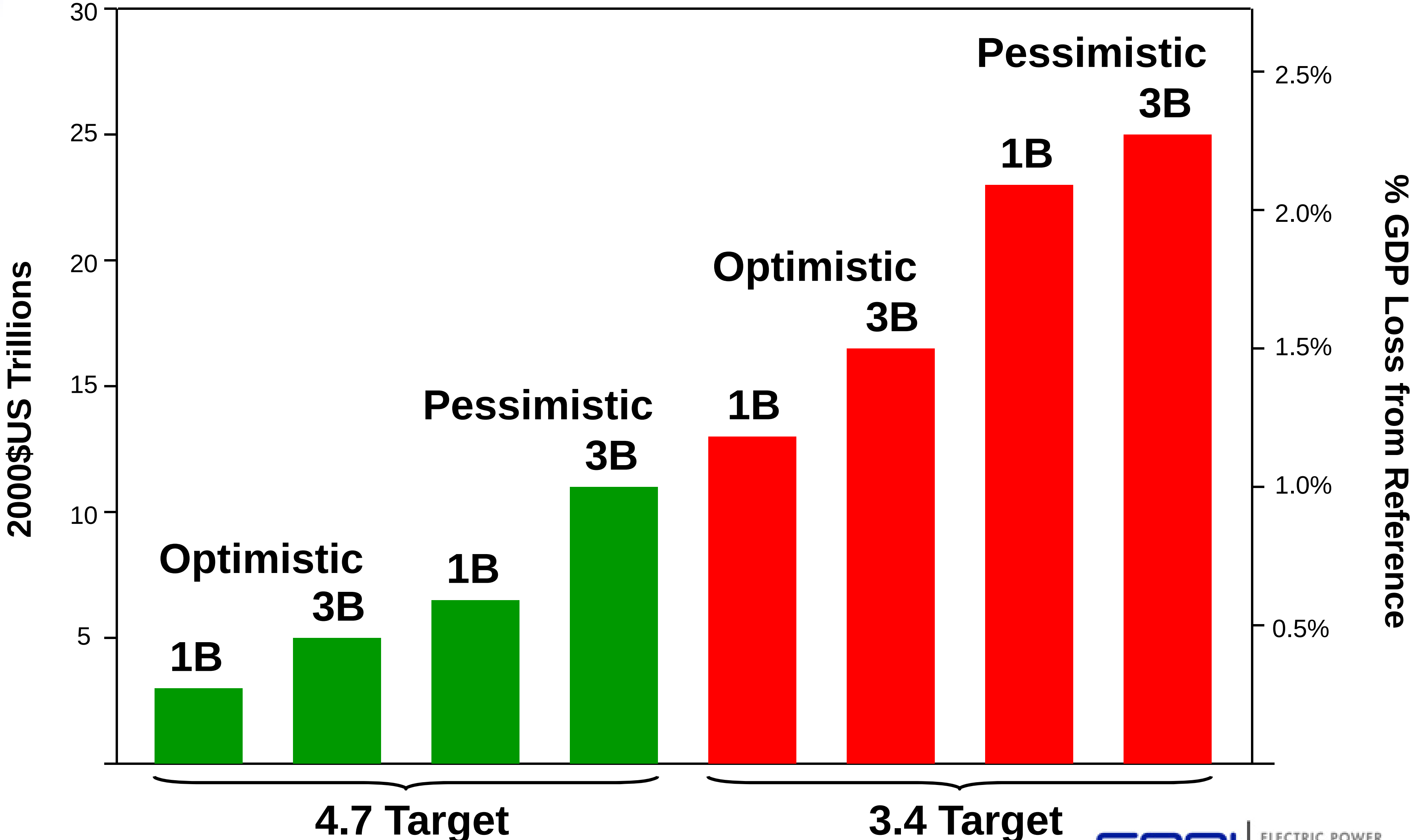
Global Discounted Sum of Economic Cost

At 5% through 2200



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