HARVARD UNIVERSITY
JOHN F. KENNEDY SCHOOL OF GOVERNMENT

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Expert elicitation of cost, performance, and RD&D budgets for greenhouse gas reducing technologies

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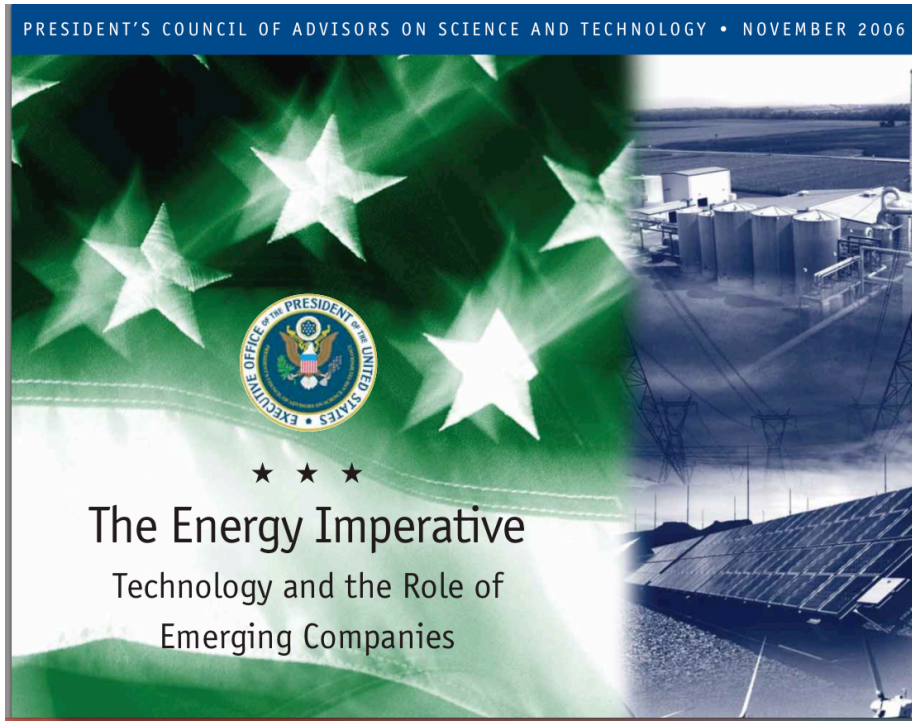
Melissa Chan
Laura Diaz Anadon

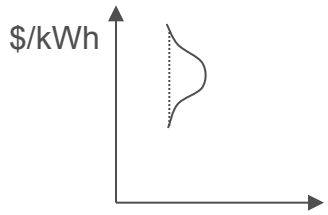
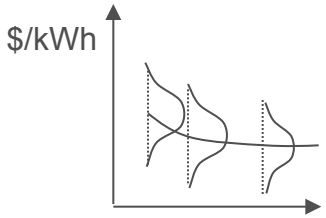
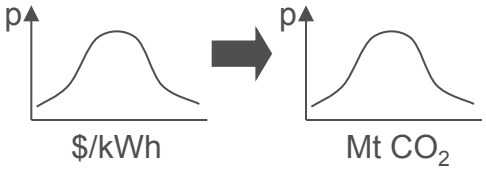
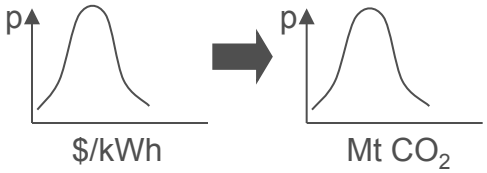
Motivation



"An abundant supply of clean and affordable energy is vital to the economic growth, quality of life, and security of the United States. Energy provides essential services for many aspects of modern life. In recent years, however, economic and political factors have stressed the global supply of oil and natural gas, driving the prices of these commodities to new highs and increasing the risk of a damaging energy shock. Meanwhile, increases in greenhouse gas emissions, in part resulting from fossil fuel combustion, are linked by many scientists to global climate change. Combined, these issues create an imperative for change in the Nation's energy systems and infrastructure in order to ensure national energy security while protecting the environment."

President's Council of Advisors on Science and Technology, *The Energy Imperative: Technology and the Role of Emerging Companies.* November 2006

Methodology

	Step 1. Data collection	Step 2. Modeling to evaluate deployment	Step 3. Sensitivity analysis
	E.g. utility scale solar power **Baseline**  Current public RD&D **Advanced**  Recommended public RD&D and sensitivity	*E.g. utility scale solar power*   Etc… (other 'benefits' and other RD&D levels)	*Examples of criteria for decision making:* • What RD&D investment portfolios can deliver X Mt of CO_2 reductions by 2050 with 70% confidence? • How do some key deployment factors (e.g. oil price, carbon price, biomass supply curve, buildings use, proliferation incident) affect the expected benefits? And what impacts do these factors have on portfolio selection (robust portfolio)?
ISSUES	**Potential for Advance, R&D Impact on Advance**	**Value of Technologies** Emissions, imports, GDP? Single technologies and portfolios	**R&D Allocation Under Technical and Market Uncertainties**
TOOLS	Technology Assessments Historical Analysis Expert Elicitation	Energy-Economic Models e.g. Merge, MARKAL, Minicam	Portfolio Models, Option Value Analysis, Decision Analysis

Industries
Based on DOE budget February 2008 proposal categories

- Advanced fossil technologies
- Solar energy
- Biomass and biorefinery systems
- Wind energy
- Smart grid
- Geothermal technology
- Carbon capture
- Vehicle technologies
- Building technologies
- Nuclear energy
- Transmission and distribution
- Energy storage

Survey overview (1 of 3)

- Part 1. Background data
  - Purpose: provide common starting point for experts; ensure methods are understood
  - Briefing for experts
    - Current federal spending and total venture capital and private equity investments
    - Current costs and performance
  - Explanation of bias and overconfidence
    - Probabilistic estimates
    - Warning to beware of overconfidence and bias
- Part 2. Self assessment of expertise
  - Purpose: experts must think about their technology knowledge; provide weights that can be used to combine data pool
- Part 3. Baseline costs & performance
  - Purpose: collect expert opinion on current and future cost and performance if current federal spending does not change

Survey overview (2 of 3)

- Part 4. Budget recommendations
  - Purpose: obtain expert opinion on total budget; determine how budget should be allocated
  - Budget amount (X = current spending)
    - 0.5X, X, 1.5X, 2X, 2.5X, 3X, etc.
  - Budget allocation
    - Specific technology areas
    - Research needs within the innovation process

Survey overview (3 of 3)

- Part 5. Post enhanced RD&D performance and cost
  - Purpose: collect expert opinion about cost and performance with modified federal spending
  - Assess sensitivity to varied spending levels
  - Identify specific, novel technologies
  - Identify spillover technologies

- Appendices
  - Technology descriptions
  - Explanation of how answers will be converted into MARKAL inputs
    - Equal weight
    - Weighting per self-assessed expertise
    - Other possibilities

Selected preliminary results
Bioenergy expert elicitation

- Survey writing and testing, February – July 2009
  - Thank you, Bob Wallace at the PennState Bioenergy bridge project for your time!
- Elicitation phase
  - Started August 2009
  - 72 experts contacted, 21 replied
    - 4 declined due to time constraints or misunderstanding the task
    - 4 completed as of October 2009
- Expert pool (17 as of October 2009)
  - Industry
  - National laboratories
  - Academia

Selected preliminary results
Recommendation of a new spending level

Existing federal bioenergy budget (2009)$220 million

USDA	DOE	
$20 million	$199 million	
Feedstock research	$52 million Processing and conversion research	$147 million Utilization

Experts' recommended bioenergy budgets (2009$)

Minimum	Average	Maximum
$300 million	$900 million	$1 billion

Expert 1	Expert 2	Expert 3	Expert 4
$1 billion	$500 million	$1 billion	$300 million

Selected preliminary results
Recommended spending on bioenergy conversion and refining

Expert recommended allocation for conversion and refining technologies (million 2009$)

KEY
(Minimum **Average** Maximum) Expert 1 2 3 4

★ = Expert priority

		Basic Research (e.g. materials, understanding fermentation reactions)	***Applied Research (e.g. reactor optimization, zeolite development)***	***Experiments and field demonstration (e.g., pilot plant)*** ★	***Commercial deployment (e.g. first of a kind plant)***
Conversion	Gasification	(2 **15** 33) 20 5 33 2	(2 **17** 30) 30 20 17 2	(4 **24** 33) 30 30 33 4	(0 **20** 50) 30 0 50 0
	Liquefaction	(4 **16** 40) 40 5 17 4	(8 **17** 30) 30 15 17 8	(0 **18** 33) 30 0 17 8	(0 **20** 50) 0 0 50 0
	Hydrolysis	(10 **17** 33) 10 10 33 16	(8 **12** 17) 10 15 17 8	(2 **24** 50) 10 50 33 2	(0 **15** 50) 10 0 50 0
	Pyrolysis ★	(6 **23** 60) 60 10 17 6	(16 **28** 60) 60 20 17 16	(18 **37** 50) 50 45 33 18	(0 **25** 50) 50 0 50 0
Refining	Catalytic reforming	(0 **10** 18) 10 10 0 18	(10 **20** 26) 10 20 25 26	(10 **22** 33) 10 30 33 14	(0 **6** 14) 10 0 0 14
	Hydrotreating	(0 **7** 16) 0 10 0 16	(0 **15** 25) 0 20 25 16	(10 **28** 40) 40 30 33 10	(0 **10** 40) 40 0 0 0
	Transesterification	(0 **0** 0) 0 0 0 0	(0 **7** 20) 20 0 8 0	(0 **4** 17) 0 0 17 0	(0 **0** 0) 0 0 0 0
	Cross-transesterification	(0 **3** 10) 10 0 0 0	(0 **5** 10) 10 0 8 0	(0 **7** 17) 10 0 17 0	(0 **3** 10) 10 0 0 0
	Fermentation	(0 **10** 15) 10 15 0 14	(8 **16** 25) 10 20 25 8	(10 **27** 42) 10 40 42 0	(0 **0** 0) 0 0 0 0
	Membrane separation	(0 **14** 30) 30 10 0 16	(6 **17** 30) 30 15 17 6	(0 **15** 25) 0 25 25 0	(0 **0** 0) 0 0 0 0
	Micro-emulsification	(0 **3** 10) 10 0 0 0	(0 **3** 10) 10 0 0 0	(0 **0** 0) 0 0 0 0	(0 **0** 0) 0 0 0 0
	Solvent based extraction	(0 **15** 50) 50 0 0 10	(0 **18** 40) 40 0 25 6	(0 **21** 42) 40 0 42 0	(0 **10** 40) 40 0 0 0

Selected preliminary results
Recommended "other" topics and spending

- Experts 1, 2, and 3 recommended other topics for spending

Expert recommended spending on other bioenergy topics (million 2009$)

		Basic Research (e.g. materials, understanding fermentation reactions)	***Applied Research (e.g. reactor optimization, zeolite development)***	***Experiments and field demonstration (e.g., pilot plant)***	***Commercial deployment (e.g. first of a kind plant)***
Other	Harvest, transport, storage	(2 **18** 33) 2	(0 **4** 13) 13	(0 **25** 40) 35	(0 **0** 0) 0
	DME	20	0	40	0
	Environmental, sustainability, economic, jobs & social impact	33	0	0	0

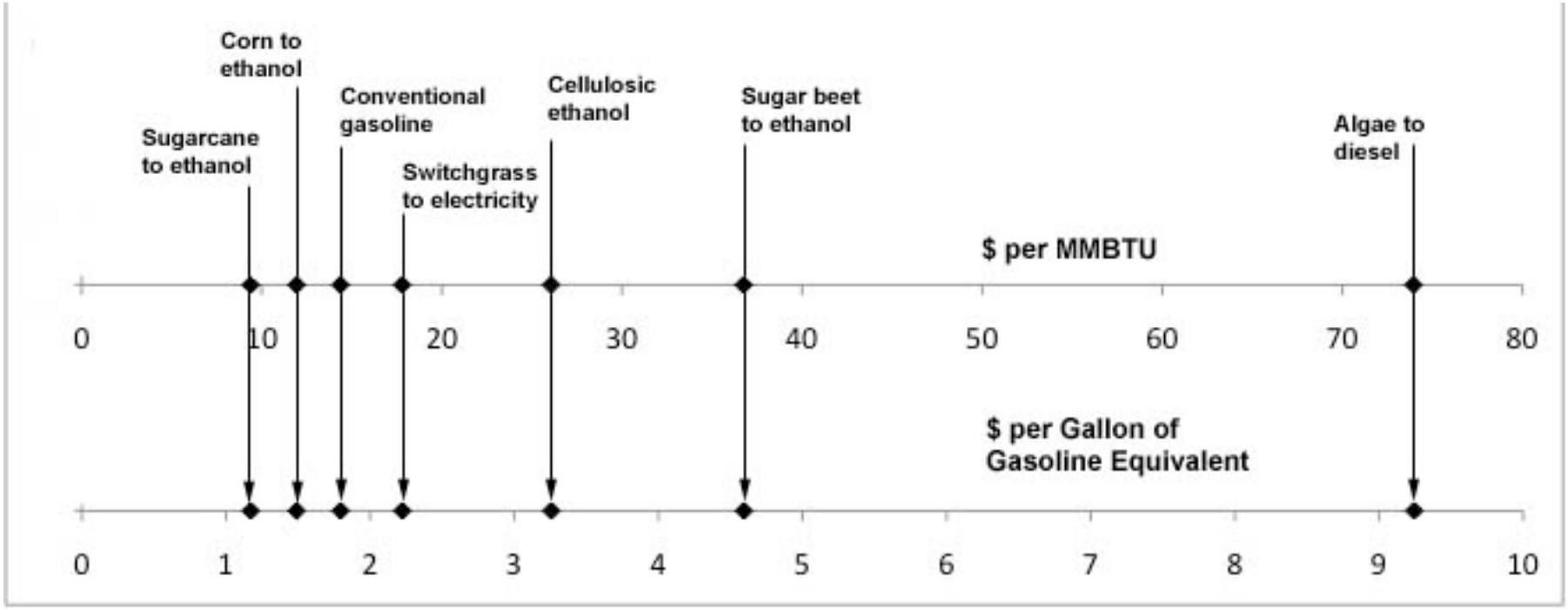
Expert believes that feedstock costs should be reduced with research

Expert believes DME-specific engines should be developed

Expert believes DME-specific vehicle should be demonstrated

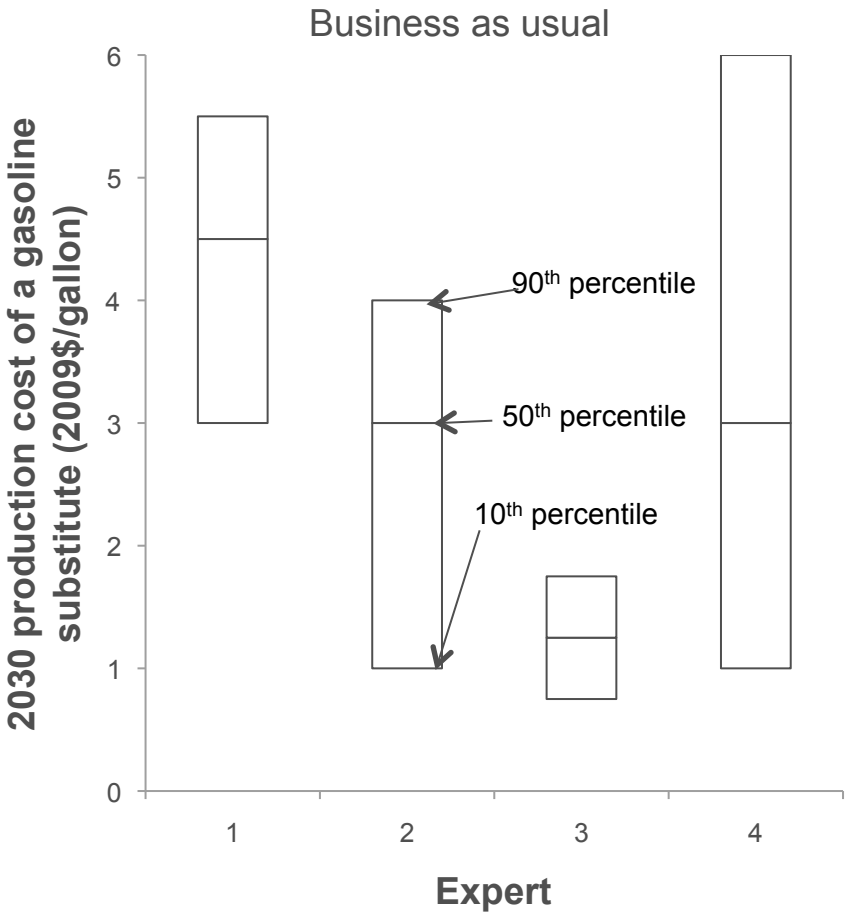
KEY
(Minimum **Average** Maximum) Expert 1 2 3 4

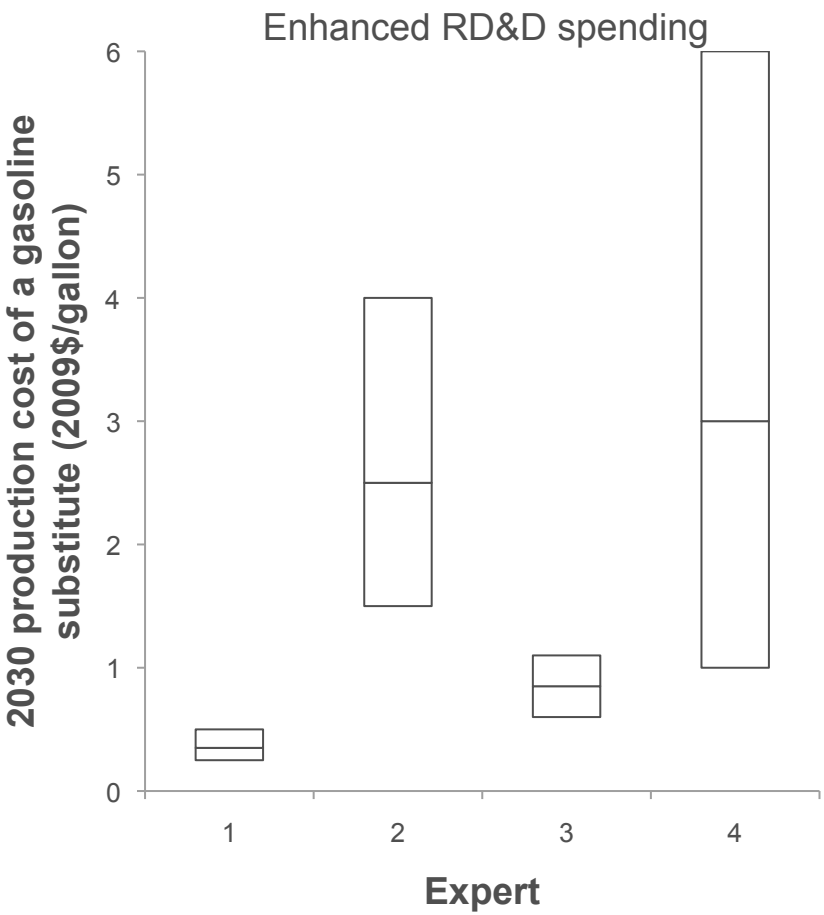
Selected background data
Cost of producing liquid fuels and electricity from biomass



Selected preliminary results

Gasoline substitute production costs under BAU RD&D spending and enhanced BAU RD&D spending





Products: Butanol, HCNG and CNG from biogas, ethanol, F-T naptha, grain ethanol, gasification-based synthetic gasoline, pyrolysis- based synthetic gasoline, cellulosic and corn ethanol, methanol, biogasoline from catalytic conversion

Products: Biogasoline from grassy cellulose via hydrolysis and catalytic reforming, ethanol from biomass via fermentation, synthetic gasoline from cellulose via pyrolysis and catalytic reforming, biobutanol from gasification

How we will use our survey results
Overview

1. Summarize results per technology area

Identifying information is removed

Experts will receive summarized results

Publication

2. RD&D scenario analysis in MARKAL

PDFs of experts' 2030 technology cost and performance

Sensitivity analyses

For example…
Deployment incentives

Hurdle rates

High fossil fuel prices

Carbon taxes

Technology deployment time and market share

Fuel consumption by type

Greenhouse gas emissions

Energy Technology Innovation Policy Project
Energy Research and Development, Demonstration and Deployment (ERD3)

- Thank you to the Doris Duke Charitable Foundation
- Contact
  - melissa_chan@ksg.harvard.edu
  - laura_diaz_anadon@harvard.edu

http://energytechnologypolicy.org