Managing R&D Risk In Renewable Energy

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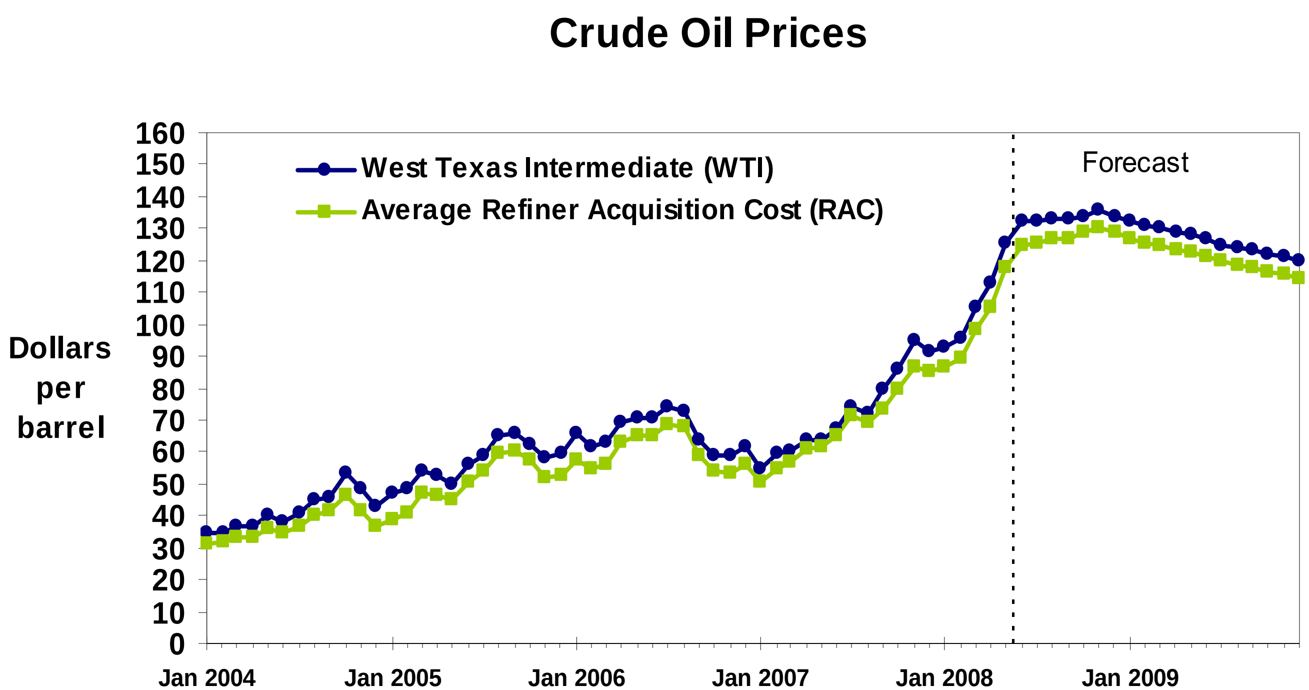
External Forces

- Crude Oil Prices
- Natural Gas Prices
- Coal Prices
- Corn Prices
- Other External Forces
- In contrast to 1970s, are they sustainable?

Renewable R&D Investment Drivers

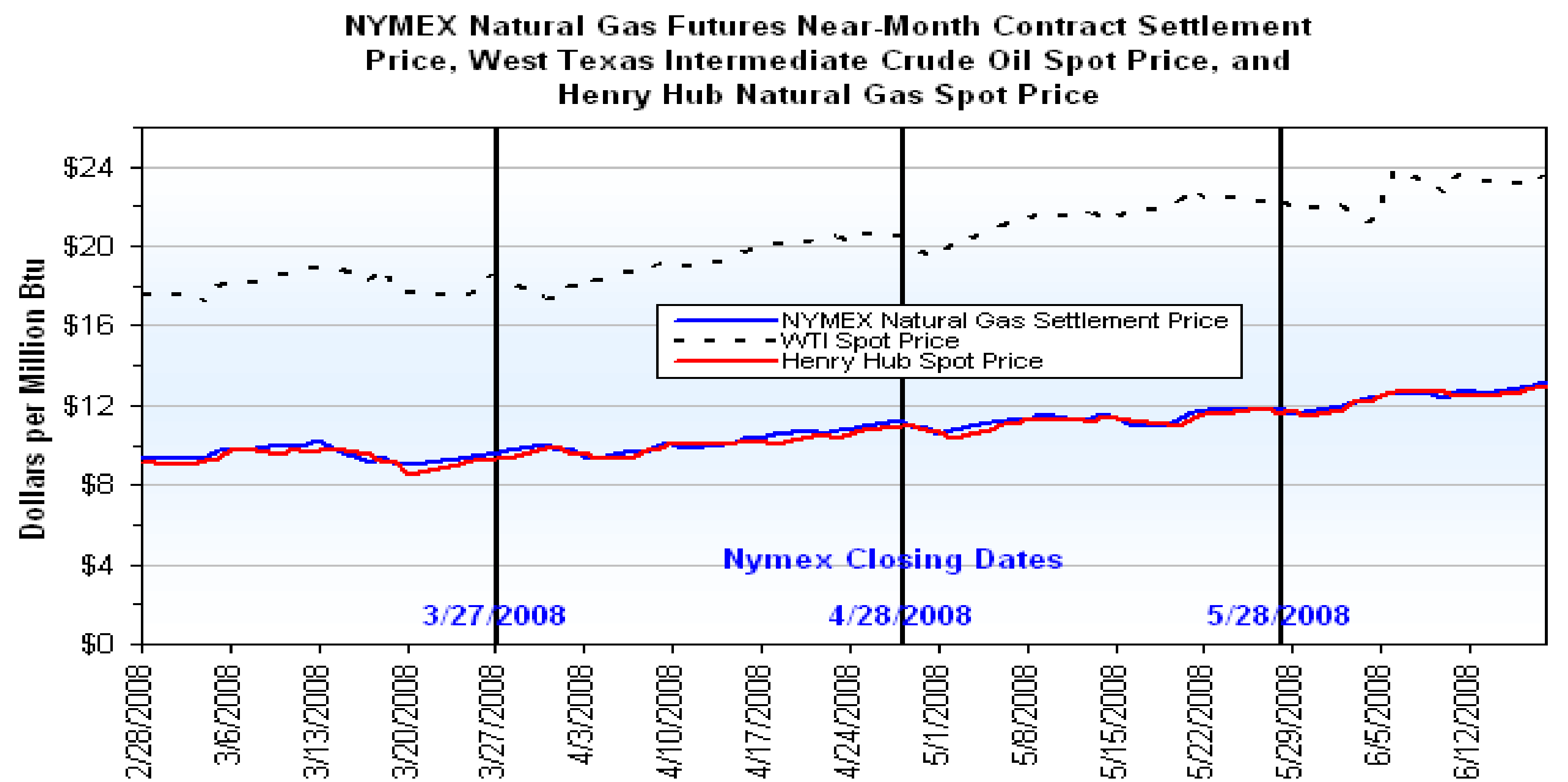
Crude Oil Prices are breaking records

- Crude oil record $138/barrel
- Gasoline $4.05/gallon; Diesel $4.79/gallon



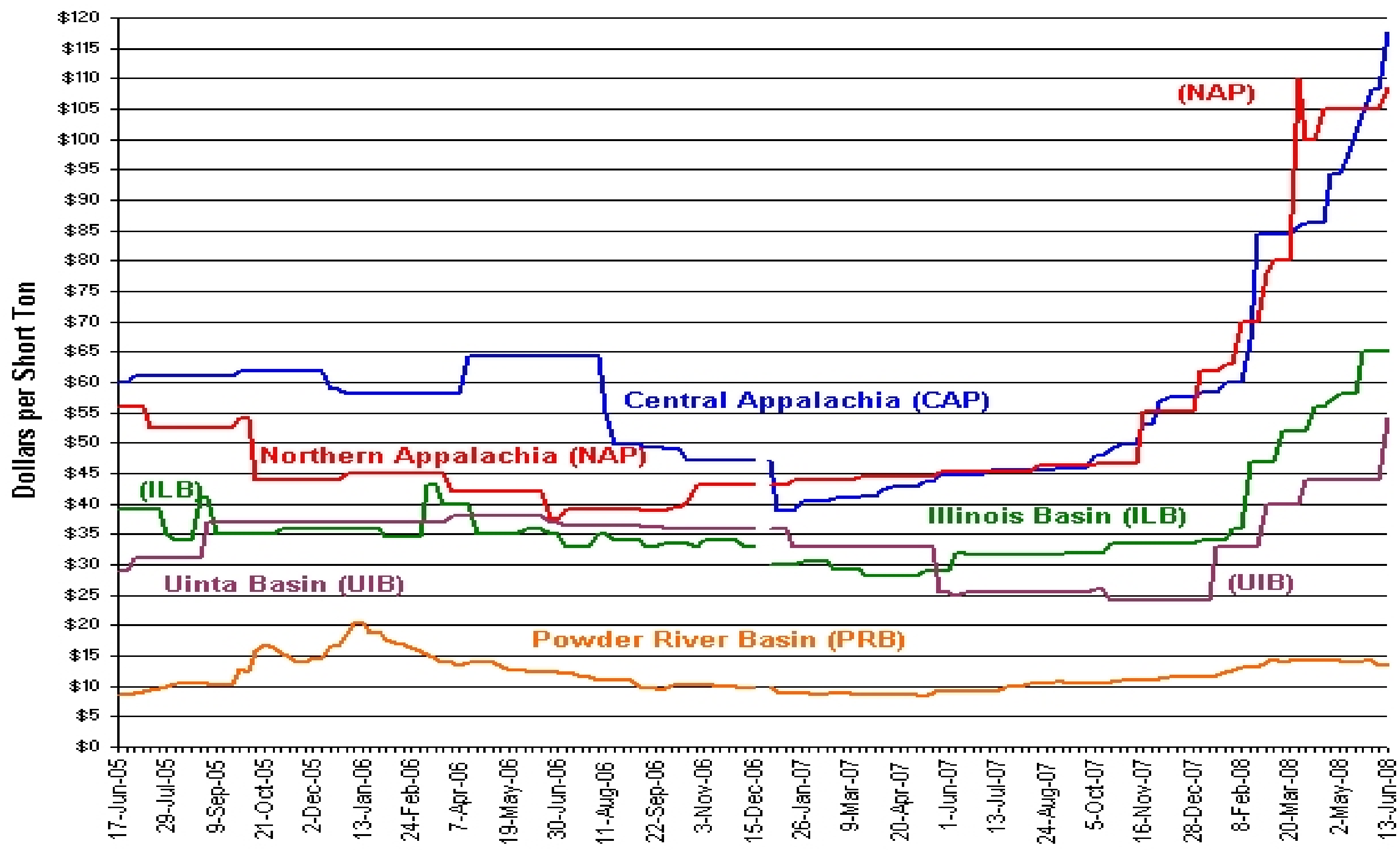
Short-Term Energy Outlook, June 2008

Natural Gas is trending upwards



Note: The West Texas Intermediate (WTI) crude oil price, in dollars per barrel, is converted to $/MMBtu using a conversion factor of 5.80 MMBtu per barrel. The dates marked by vertical lines are the NYMEX near-month contract settlement dates. Source: Natural gas prices, *NGI's Daily Gas Price Index* (http://intelligencepress.com); WTI price, Reuters News Service (http://www.reuters.com).

Coal is trending upwards

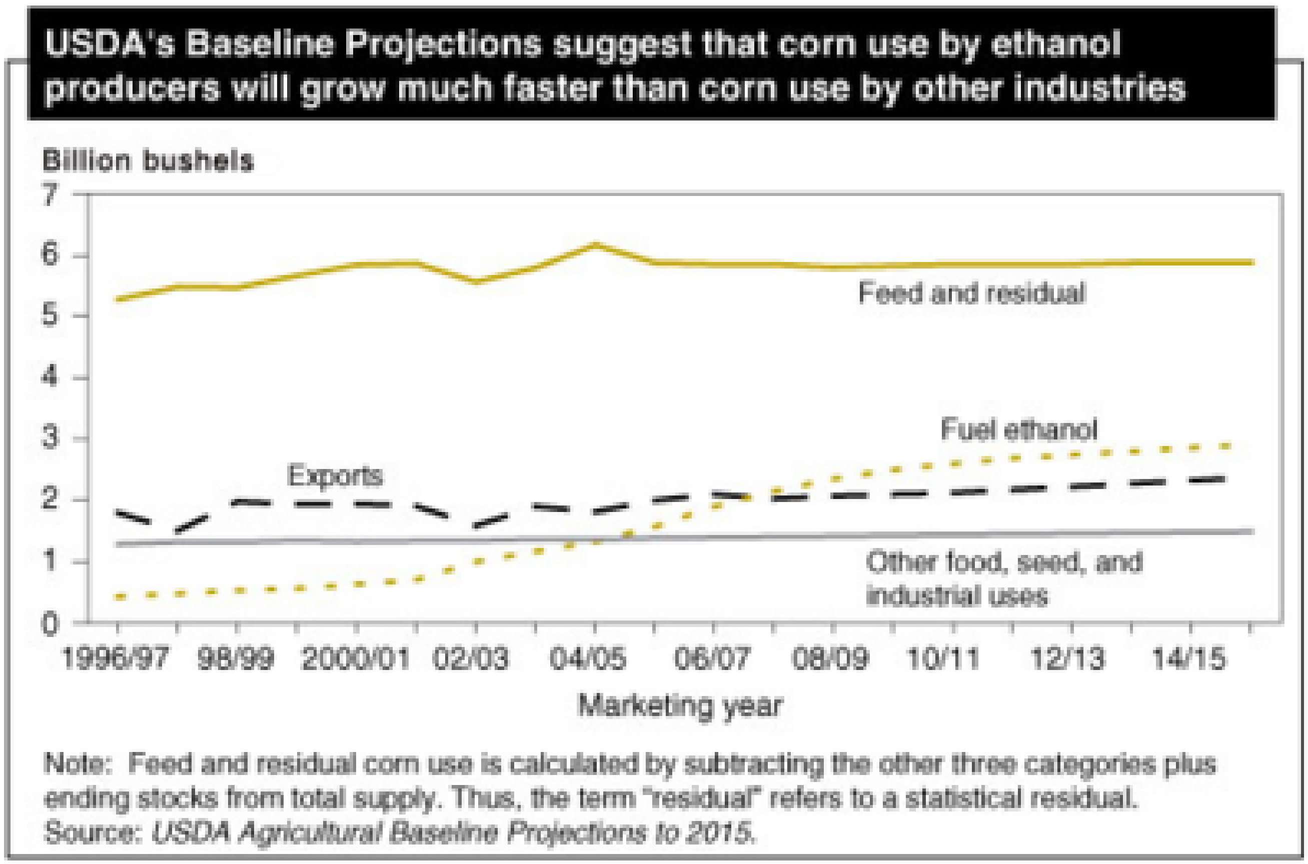


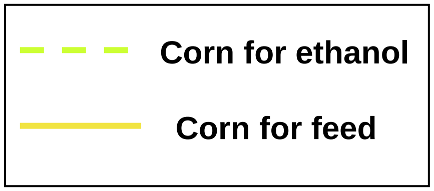
Key to Coal Commodities by Region[1]

Central Appalachia:	Big Sandy/Kanawha 12,500 Btu, 1.2 lbSO2/mmBtu	Powder River Basin:	8,800 Btu, 0.8 lb SO2/mmBtu
Northern Appalachia:	Pittsburgh Seam 13,000 Btu, <3.0 lbSO2/mmBtu	Uinta Basin in Colo.:	11,700 Btu, 0.8 lb SO2/mmBtu
Illinois Basin:	11,800 Btu, 5.0 lb SO2/mmBtu		

Corn Prices are rising

- Corn Futures: $7.03/bushel July 2008; $7.47/bushel in 2009
- Corn use for ethanol is projected to rise



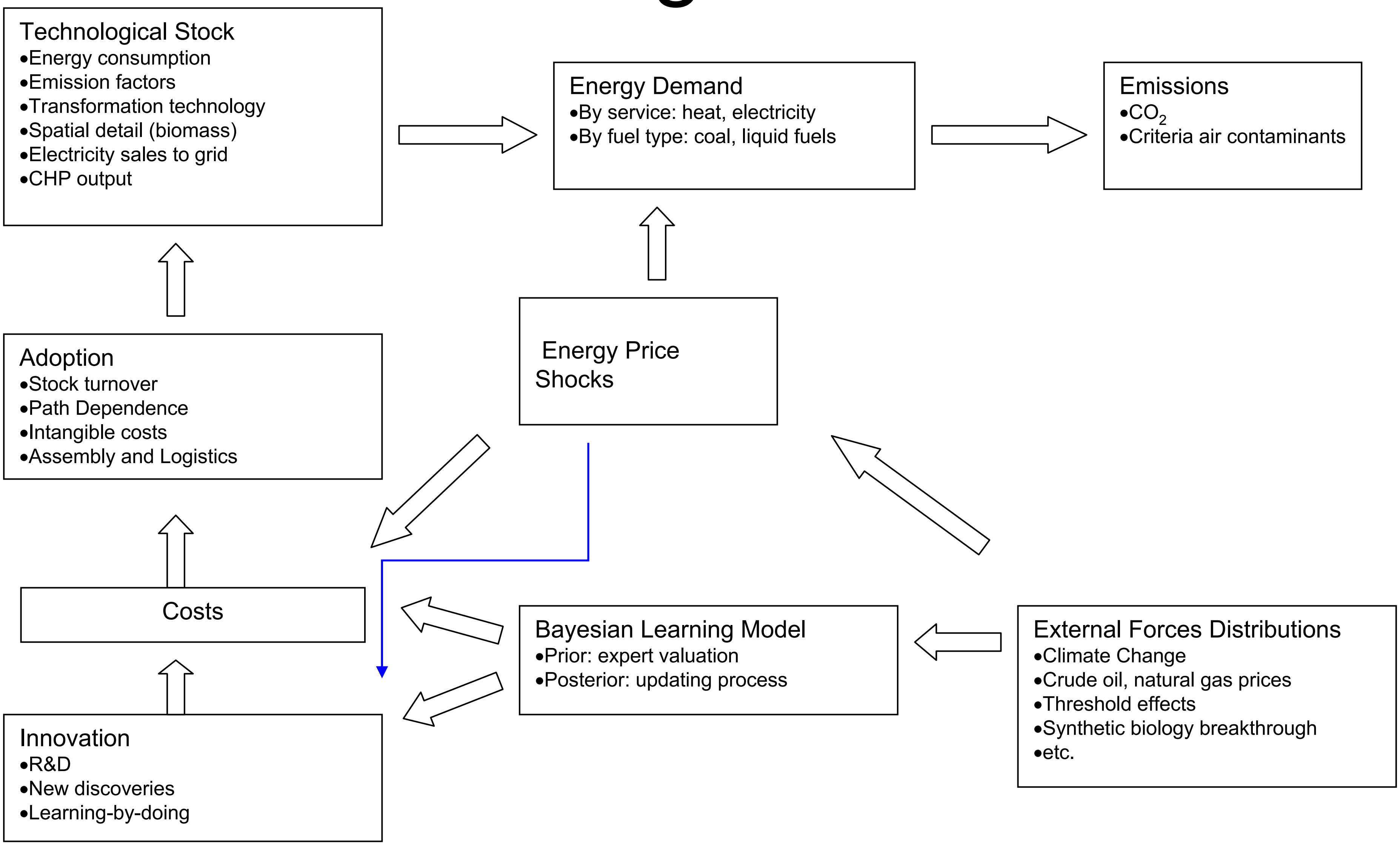


Emerging Industrialization Policies

- Subsidization of R&D Renewable Energy Technologies
- Prior Experience, e.g. Infant Industry Experience
- Brazil subsidization of sugar-based ethanol
- Lobby efforts to maintain subsidization
- Commercial market subsidies: biofuel mandates, tax credits, credit subsidies, risk swaps, price subsidization, input subsidies, trade protection

- Proposed Framework: Ex-Ante allocation of renewable energy investment across emerging technologies using modern portfolio analysis under risk and uncertainty.
- Avoid privatisation of upside and socialization of downside risks

The Big Picture



Renewable R&D Landscape

Public Sector

DOE Renewable Energy Milestones

Cellulosic Ethanol	cellulosic ethanol cost competitive with conventional ethanol by 2012
	replace 30% of today's gasoline in 2030 with biofuels
Hydrogen	industry commercialization possible by 2015
	fuel cell vehicles in the showroom and hydrogen at fueling stations by 2020
Solar	reduce solar costs to grid parity in all U.S. markets by 2015
Wind	reduce cost of energy from large systems to 3 cents\kwh by 2010
	greatly expanded deployment of distributed wind energy by 2016
	large-scale offshore wind and hydrogen production from wind by 2020

Share of Federal Renewable Energy R&D has increased:

Table 2: Federal Energy R&D ($Millions)			
	Total Energy	Renewable	Share of total
1990	4,047	381	0.09
1991	3,844	482	0.13
1992	3,940	558	0.14
1993	3,316	613	0.18
1994	3,475	719	0.21
1995	3,355	770	0.23
1996	2,908	644	0.22
1997	2,638	627	0.24
1998	2,810	699	0.25
1999	3,111	763	0.25
2000	3,036	746	0.25
2001	3,401	800	0.24
2002	3,580	825	0.23
2003	3,425	779	0.23
2004	3,418	712	0.21
2005	3,361	693	0.21

← 9% in 1990

← 21% in 2005

Biomass R&D Funds Have Increased

DOE and USDA Biomass R&D ($M)		
	USDA	DOE
2002	5	92
2003	14	86
2004	14	69
2005	14	89
2006	12	90
2007	12	150

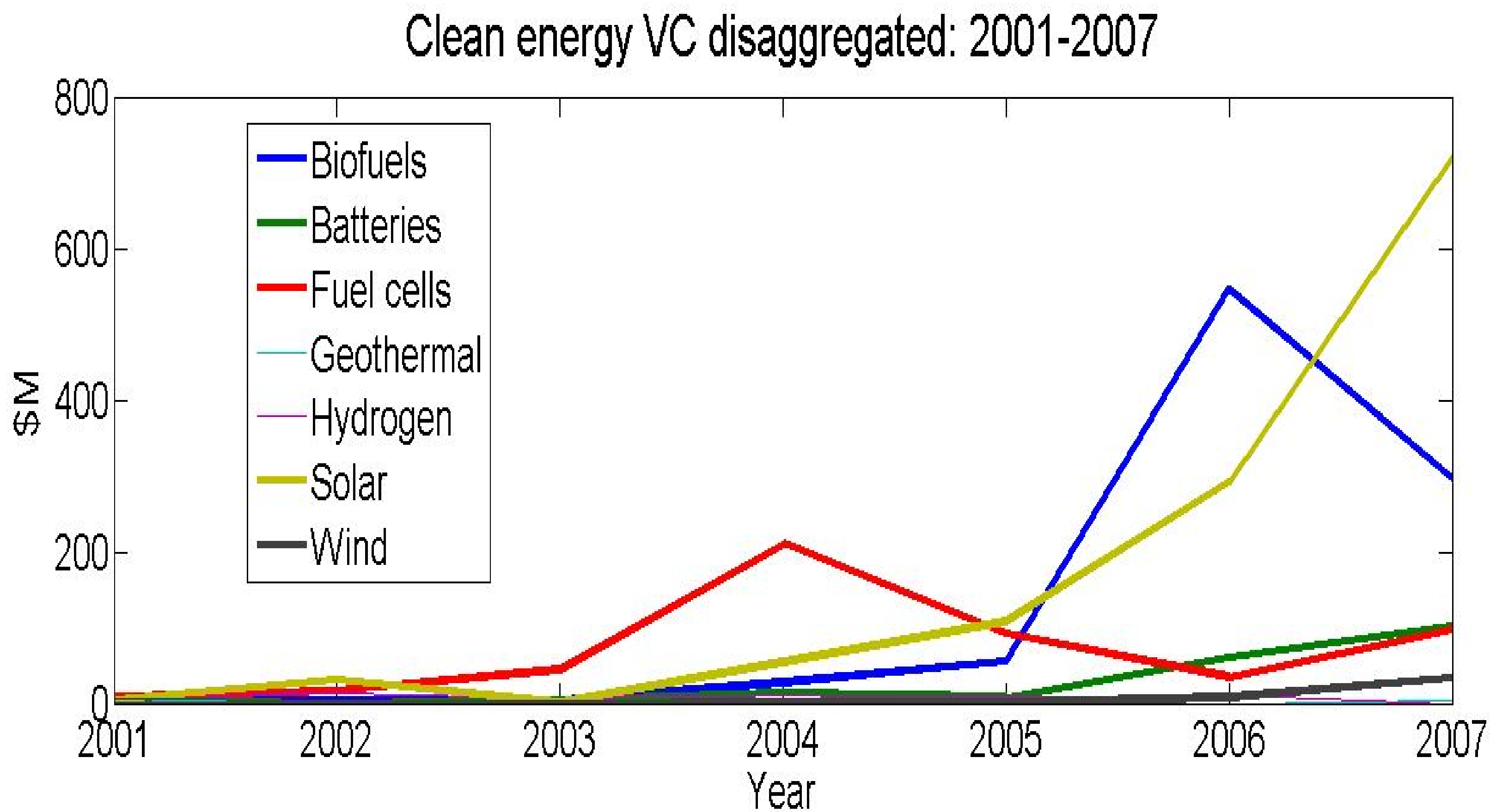
Solar, Wind, Geothermal and Energy Storage R&D Funds Have Decreased

Federal Energy R&D Breakdown ($M)				
	Batteries	Solar	Wind	Geothermal
2001	7	105	45	30
2002	78	100	43	30
2003	93	90	45	31
2004	9	86	42	26
2005	4	87	42	26
2006	3	83	39	23

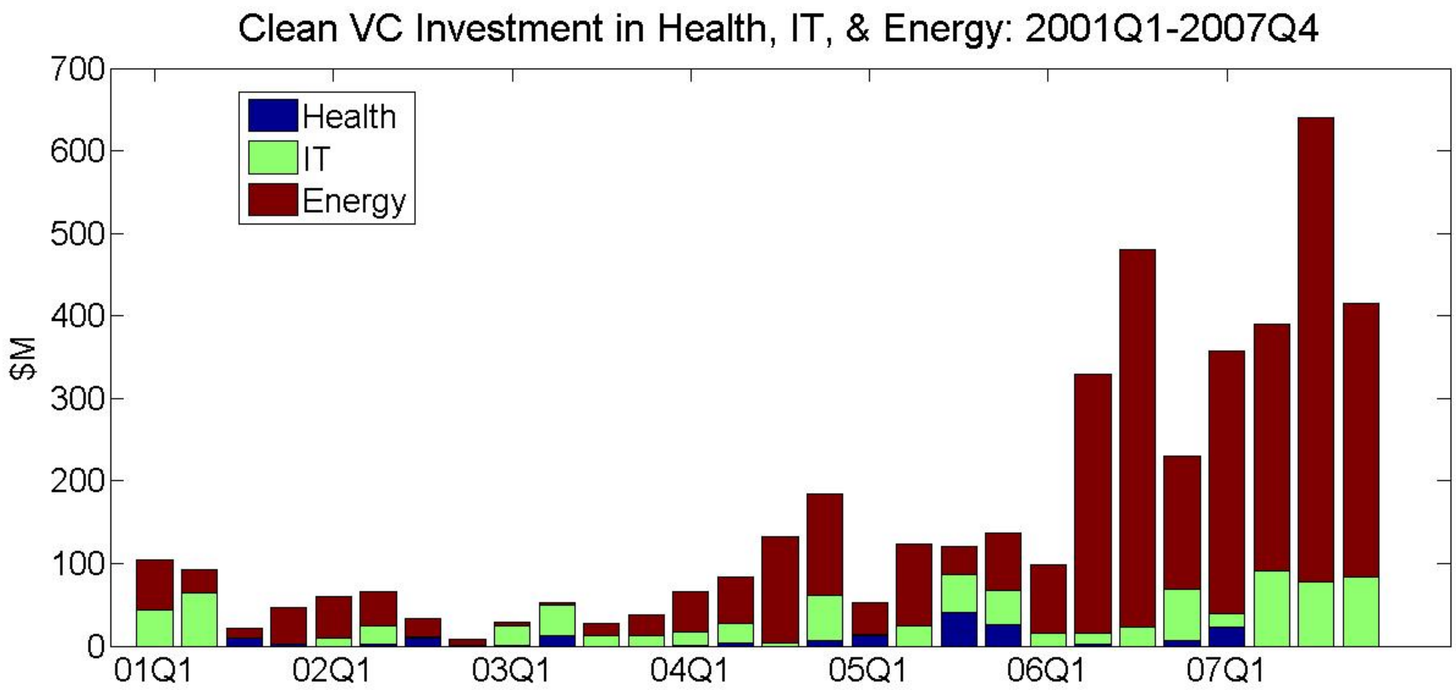
Current Legislation

- Energy Independence and Security Act
  - 36 billion gallon mandate for renewable fuels by 2022, up from 9 billion in 2008
  - Authorizes $500 million annually from 2008-2015 for production of advanced fuels that yield at least a 80 percent reduction in lifecycle GHGs
- 2008 Farm Bill
  - Approved a $1.01 per gallon credit for cellulosic biofuels
  - Dropped the subsidy to 45 cents per gallon for conventional ethanol
- Tax credits of 1.5 cents per kWh for energy produced from wind, solar, geothermal or certain types of biomass

Private Sector Has Responded to Favorable Investment Conditions



Increasing exposure in the renewable energy market



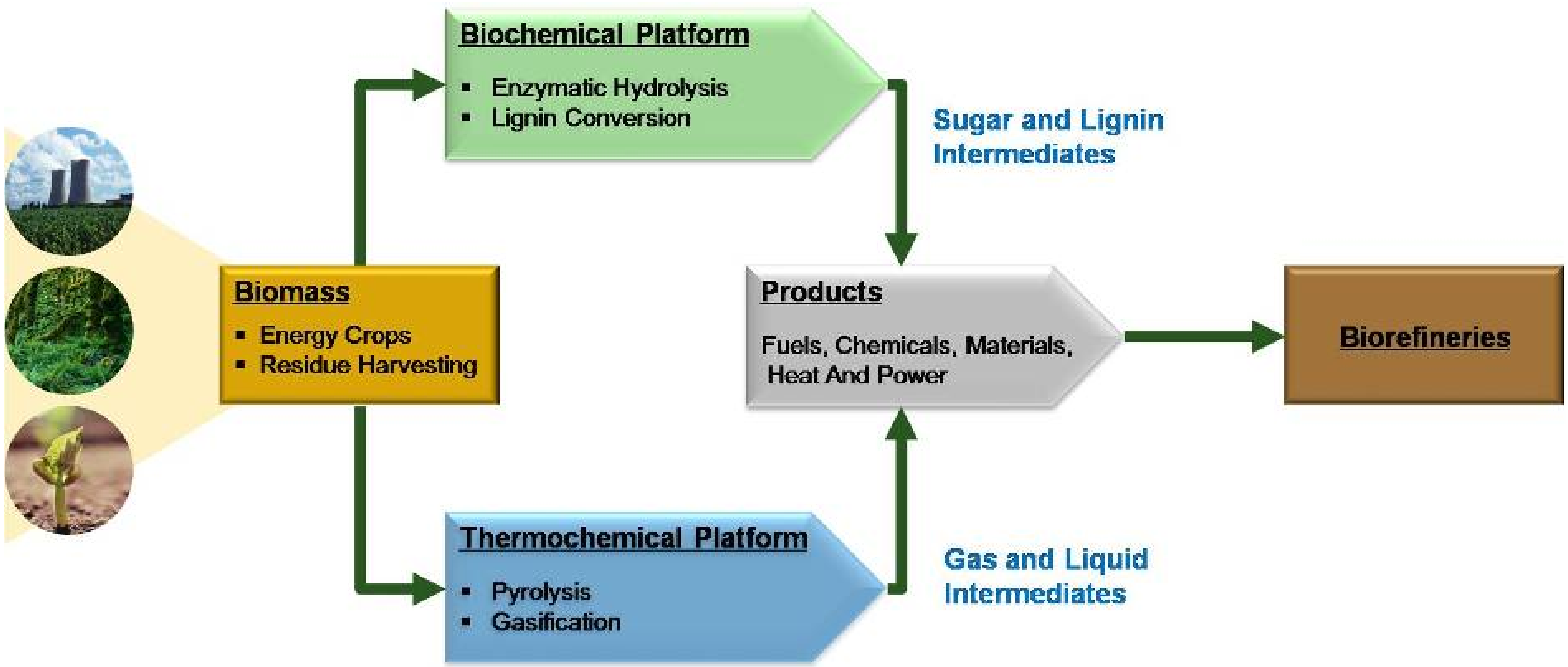
Public-Private Partnerships

- UC Berkeley – LBNL – University of Illinois – BP
  - Energy Biosciences Institute
  - $500 million over ten years
- UC Davis – Chevron
  - Cellulosic ethanol
  - $25 million over 5 years
- Iowa State – Conoco-Phillips – NREL
  - Cellulosic Ethanol, Pyrolysis, Gasification
  - $22.5 million over 8 years

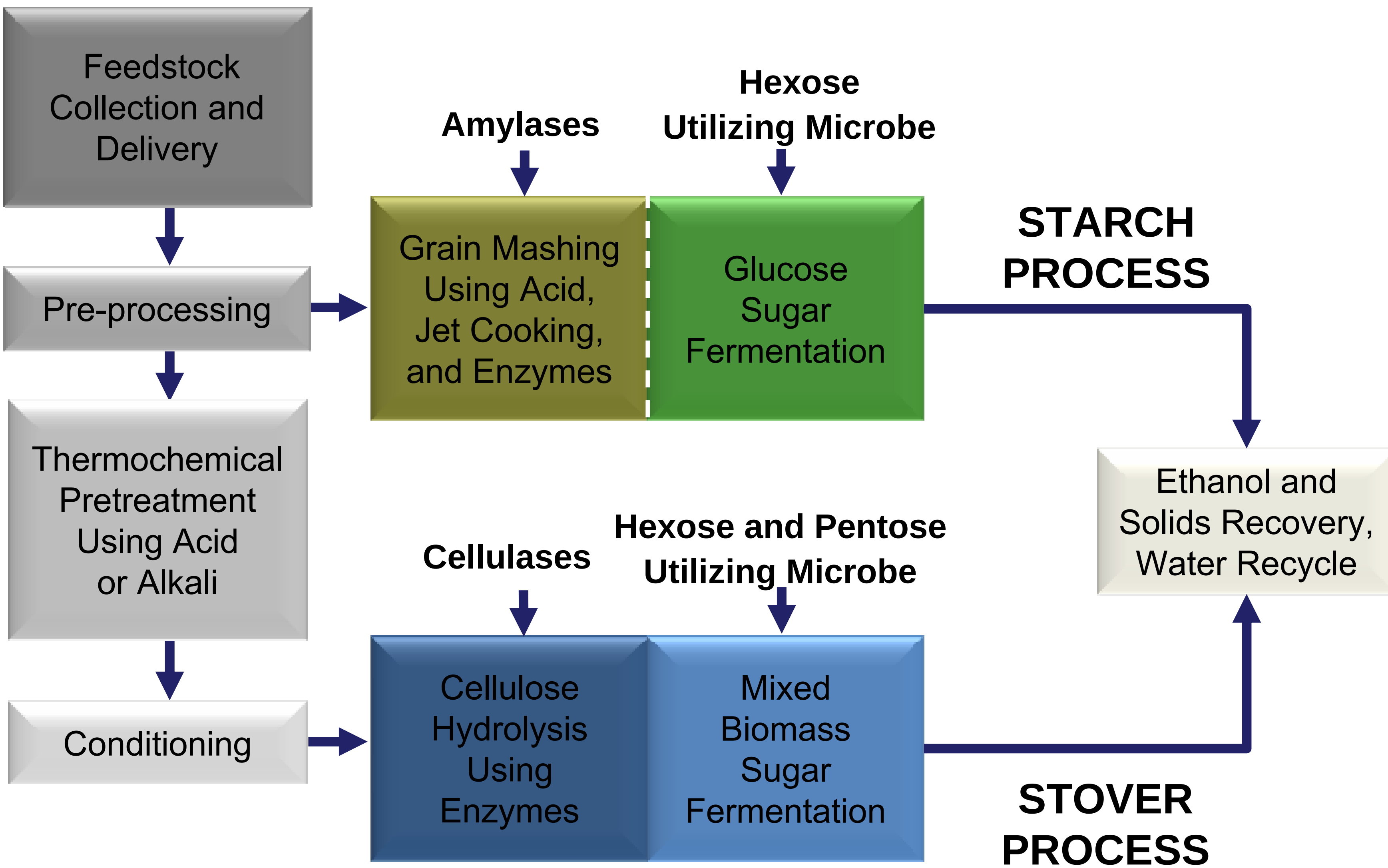
Potential Breakthroughs in Renewable Energy Technologies

- Biofuels
- Hydrogen
- Hybrid and Electric Vehicles
- Biomass for Electricity Production
- Solar Energy
- Wind Energy

Alternative Paths to Ethanol Production



The Ethanol Production Process



Biofuels: Potential Breakthrough Areas

Cellulosic Ethanol

-Depolymerization/Hydrolysis

-New Microbes

-New Catalysts

Feedstock Development:

-Miscanthus

-Switchgrass

-Wood

-Agricultural Waste

Biodiesel

-Cellulosic Biomass

-Algae

-Waste

Conventional Ethanol

-Corn Seed Genetics

-New Enzymes

DOE Ethanol Research Timeline

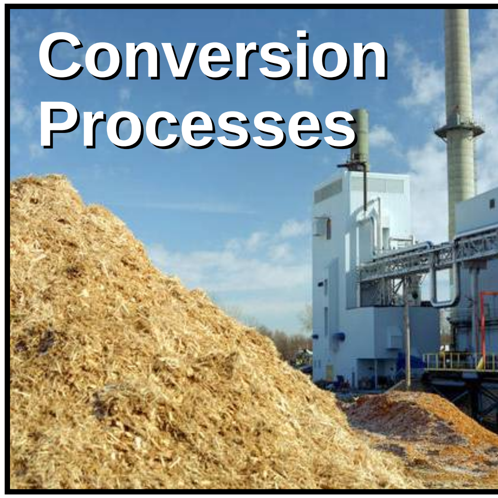
Within 5 Years	Within 10 Years	Within 15 Years
Research Phase	**Deployment Phase**	**Integration Phase**
•Methods for cellulosic feedstock harvest and conversion to ethanol •Enzymatic breakdown to 5- & 6-carbon sugars & lignin •Use of Thermo- and Biochemical Conversion	•Creation of new generation of energy crops •Breakdown of biomass to sugars & cofermentation of sugars via new biological systems •Enhanced substrate range, temperature & inhibitor tolerance	•Spur flexible biorefineries •Refineries tailored for specific agroecosystems •New & improved enzymes for breaking down biomass into sugars

Range of Possible Biorefinery Concepts

Biomass Feedstock

- Trees
- Grasses
- Agricultural Crops
- Residues
- Animal Wastes
- Municipal Solid Waste
- Algae
- Food Oils

Conversion Processes



- Enzymatic Fermentation
- Gas/liquid Fermentation
- Acid Hydrolysis/ Fermentation
- Gasification
- Combustion
- Co-firing
- Trans-esterification

Products

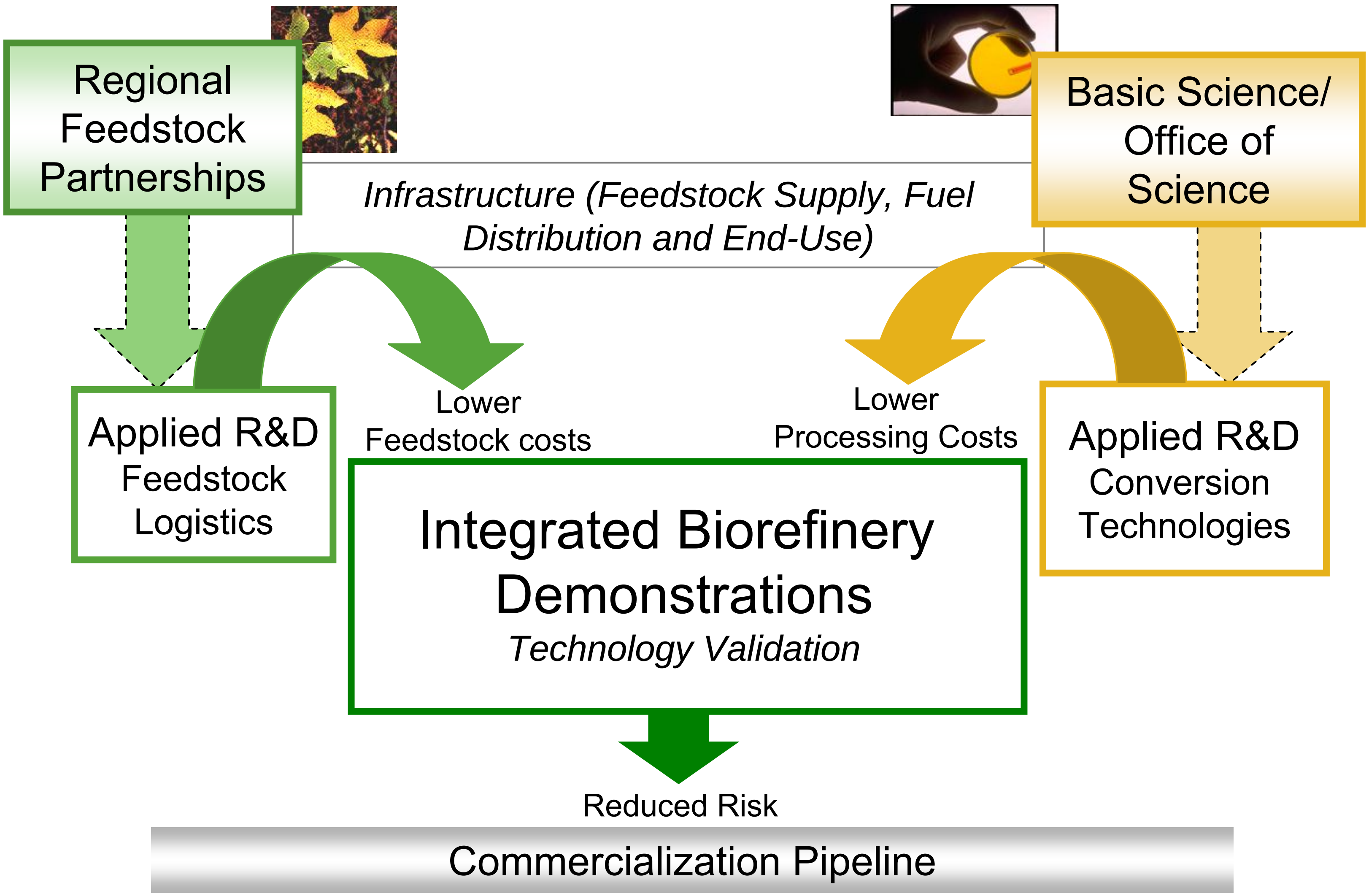
Fuels
- Ethanol
- Biodiesel
- “Green” Gasoline & Diesel

Power
- Electricity
- Heat

Chemicals
- Plastics
- Solvents
- Chemical Intermediates
- Phenolics
- Adhesives
- Furfural
- Fatty Acids
- Acetic Acid
- Carbon Black
- Paints
- Dyes, Pigments, and Ink
- Detergents
- Etc.

Food and Feed

Strategic Approach



Other Renewable Technologies

Hydrogen Breakthrough Potential

Storage Capacity

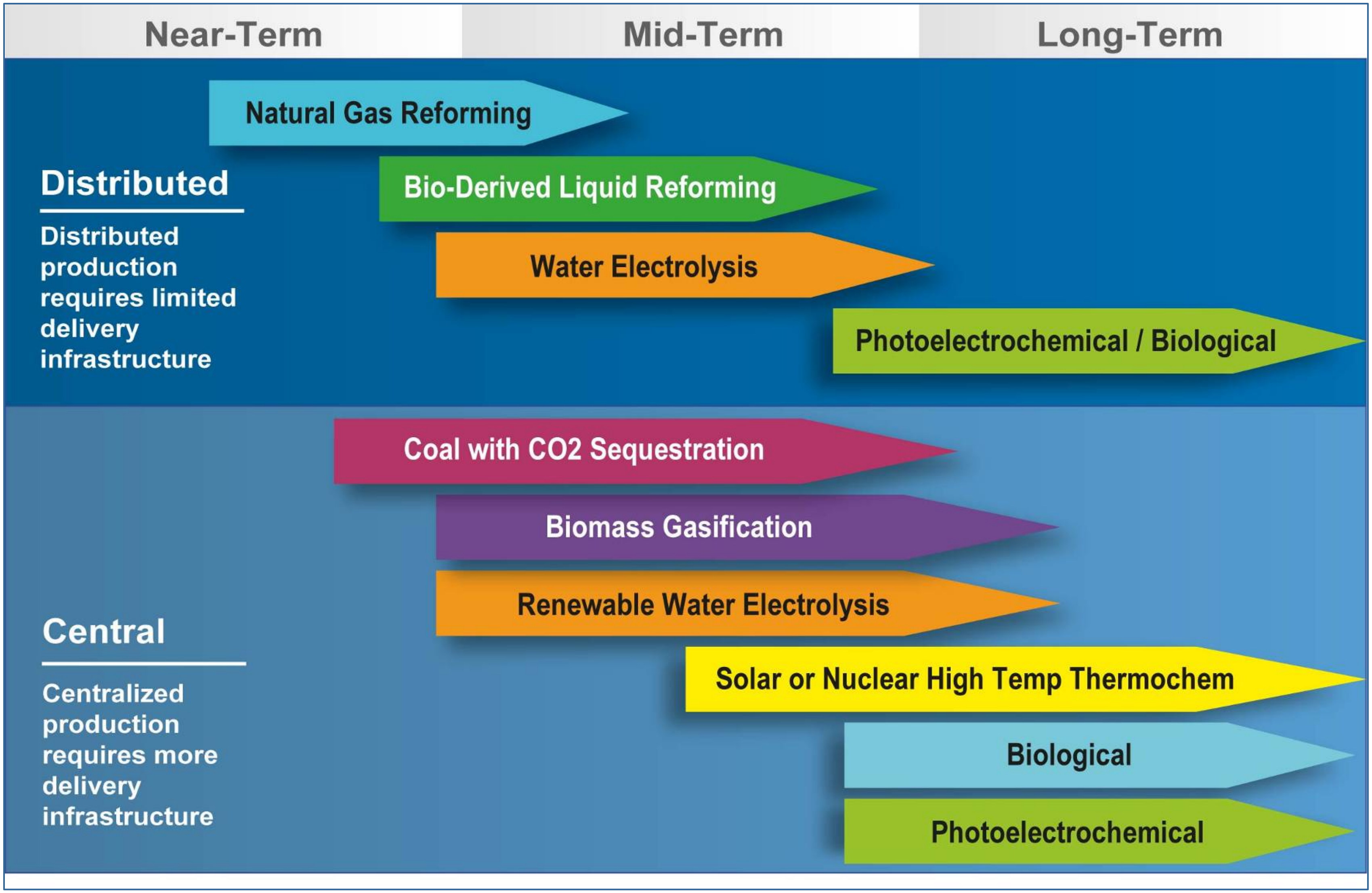
- High-density hydrogen storage
- Solid hydrogen fuel
- Hydrogen storage with carbon nanotubes
- Reduced Vehicle Weights

‘Clean’ Hydrogen Production

- Electrolysis
- Photoelectrochemical splitting
- Biomass anaerobic digestion
- Hydrogen-producing algae and bacteria

HYDROGEN PRODUCTION:
Pathways

GOAL: Clean, diverse domestic pathways for cost effective hydrogen production.



Hybrid/Electric Vehicle Potential Breakthroughs

- Greater energy density → Smaller battery size
- Longer Battery Life:

  -less degradation with age

Solar Energy Breakthroughs

Thin-Film PV

- New materials:
  - amorphous silicon
  - copper diselenide
  - Cadmium telluride

•Increased Efficiency

•Improved manufacturing process

•Long-Term Outdoor Reliability

PV Concentrators

- Higher efficiencies
- More robust modules
- Improved sun-tracking arrays

Long-Term Potential Breakthroughs

Tandem Cells

- Multiple bandgaps at low cost

Nanomaterials

- Nanosize photon absorbers
- Nanowires as photon waveguides

Multiple Exciton Generation

- Multiple electron excitons per photon
- Improved efficiency through inorganic semiconductor nanocrystals

Plasmonics

- Increased cell light absorption electron density waves

Wind Energy Breakthroughs

Continued Incremental Turbine Improvement:

- lighter weight, increased capacity
- Eliminate hydraulic systems
- “Smart rotor” development
- Advanced electronic control systems

Current Costs

Renewable Energy Costs, Transportation Fuels ($/MJ)		
Gasoline Benchmark		0.012
Biofuels	corn ethanol	0.018
	corn stover	0.0236
	switchgrass	0.0354
	miscanthus	0.0242
	sugar cane (Brazil)	0.0101
	sugar cane bagasse	0.056
	biodiesel algae	n/a
	biodiesel waste grease	0.0103-0.0158
	biodiesel vegetable oil	0.016-0.020

Renewable Energy Costs, Electricity ($/MJ)		
Coal Benchmark	pulverized coal	0.011-0.014
Biomass	biomass electricity (no cogen)	0.014-0.019
	landfill gas electricity	0.008-0.01
	anaerobic digestion electricity	0.01-0.015
	hydrogen from wind	0.028-0.039
Other Renewable	solar	0.083-0.11
	wind	0.01-0.016

Production or Cost Function Representation

- Common Framework to represent each technology:

Production

$$m_{it} = r_{it} + a_{it}F(L_{it}, K_{it}, m_{it})$$

m_{it} =feedstock input, r_{it}= carbon by-product, a_{it} = *productive efficiency parameter*

or Cost

$b_{it}C_i$ = unit cost of the i-th technology at time t.

- Goal is to develop a portfolio analysis of R&D investments in renewable energy
- Elicit expert evaluation of probability distribution around future productivity improvement/cost reduction

Productivity improvement ⟶ a_{it} rises

Cost reduction ⟶ b_{it} falls

→ Computable portfolio model

→ Bayesian structured updating process

→ Generate time- and performance-dependent optimal mixed strategy across renewable energy technologies

- Determination of the Optimal Portfolio
  - Social Welfare
  - Private Sector Conditional On Public Sector Actions
  - Public Sector Decision-Making

Conclusion

- Potential uses of Risk Modelling Framework
  - Determine public sector portfolio of risk-adjusted allocation of R&D resources
  - Determine the private sector's allocation of R&D resources conditional on the current portfolio of public and other private sector investments
  - Evaluate grant proposals for potential stand-alone discovery impact versus the effect on the overall portfolio

Conclusion cont'd…

- Ex-Ante Rational Public Policy
  - Avoid pitfalls of industrialization efforts
  - Generate mixed strategies across alternative renewable energy technologies with exit clauses for terminating policy instruments that generate rents and subsidies to the private sector

Thank You