POLICY PATHWAYS TO A VIABLE RENEWABLE ENERGY SECTOR

AERE-Sponsored Sessions at the 2012 WEAI Annual Meetings
June 2012, San Francisco

Gordon Rausser and Huayong Zhi
University of California, Berkeley

1. Introduction

- All of the major countries in the world are actively engaged in attempts to jump-start their country's renewable energy industries.
- Governmental support for renewable energy is, for now, essential for commercial viability.
- Lens of industrialization policy
  - Many infant industries remain infants in perpetuity
  - Key success factors have been identified: knowledge spillovers and correction of market failures
  - Major obstacle to viable commercialization: LNG, new discovery and extraction technologies

- Global Status Report 2012
  – Renewable energy targets and support policies continued to be a driving force behind increasing markets for renewable energy, despite some setbacks resulting from a lack of long-term policy certainty and stability in many countries.
  – Renewable power generation policies remain the major type of support policy
  – Feed-in-tariffs (FITs) and renewable portfolio standards (RPS) are the most commonly used policies

- Policymakers are pursuing numerous goals
  - energy security
  - reduced import dependency
  - reduction of greenhouse gas (GHG) emissions
  - prevention of biodiversity loss
  - improved health
  - job creation
  - rural development
  - energy access

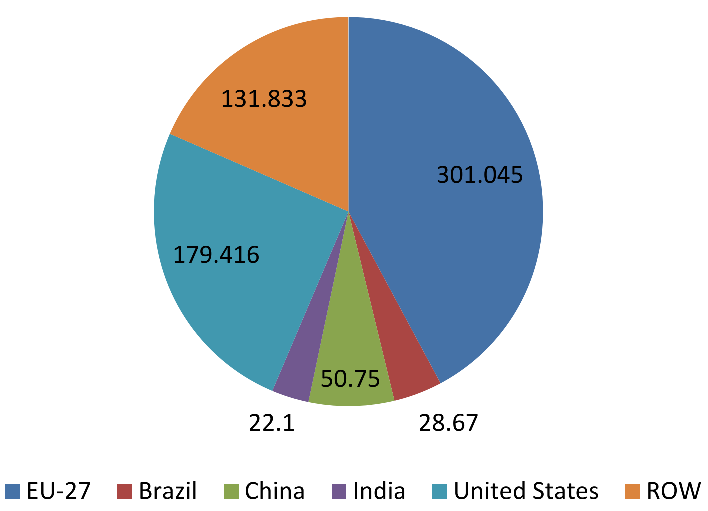
- In the implementation of industrialization policies for renewable energy, a smorgasbord of policy instruments are currently used.
- The private sector in these countries has reacted to these policy instruments with increases in renewable energy R&D and commercial investment
    - As the private sector exposure in renewable energy markets increases, public sector will increasingly be pulled by special interests in the direction of insuring against downside risk.
    - Little if any evidence exists of coordinated support of renewable energy technologies across upstream R&D investment and downstream market-based and nonmarket-based incentives.
    - Uncoordinated public sector strategies are reflected in generic approaches which are highly compartmentalized.
- Without an objective ex ante guide for public sector support, governments are likely to promote various segments of the renewable energy industry based on the effectiveness of political-economic efforts.

Public sector investment in renewable energy: The case of the US federal government

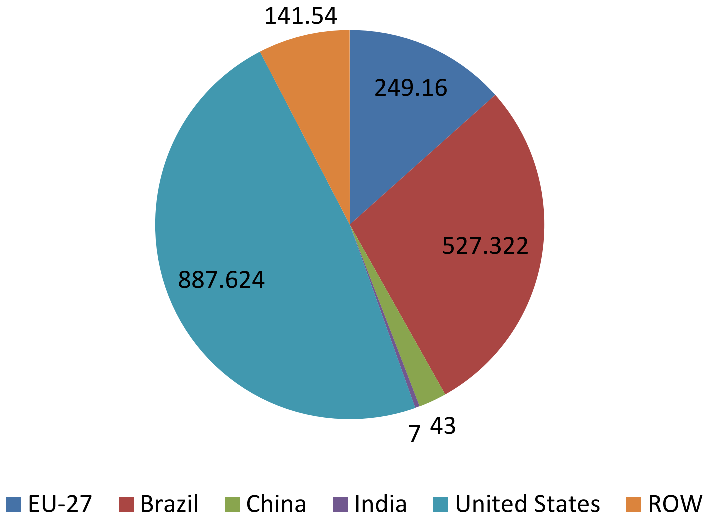
- The federal government spends less than $5 billion a year on energy R&D. $30 billion is spent annually on health R&D and more than $80 billion is spent on military R&D (American Energy Innovation Council).
- “[Sharply increasing federal spending is] the only way you‘re going to get to the goal of not driving extreme climate change without extreme pain. The fact that we‘re not getting going is terrible.” —Bill Gates, in *The Wall Street Journal*
- “When our company shifted our attention to clean energy, we found the innovation cupboard was close to bare. My partners and I found that the best fuel cells, the best energy storage, and the best wind technology were all born outside of the United States.” —John Doerr, Venture Capitalist, in *The New York Times*

2. Comparative Country Assessment

- Selected countries: Brazil, China, European Union, India, and the U.S.
  - All of these countries are actively engaged in attempting to jump-start their renewable energy industries
  - They are the major users of energy globally as well as the major developers of a nascent renewable energy sector.



Non-hydroelectric power generation (billion kWh), 2011



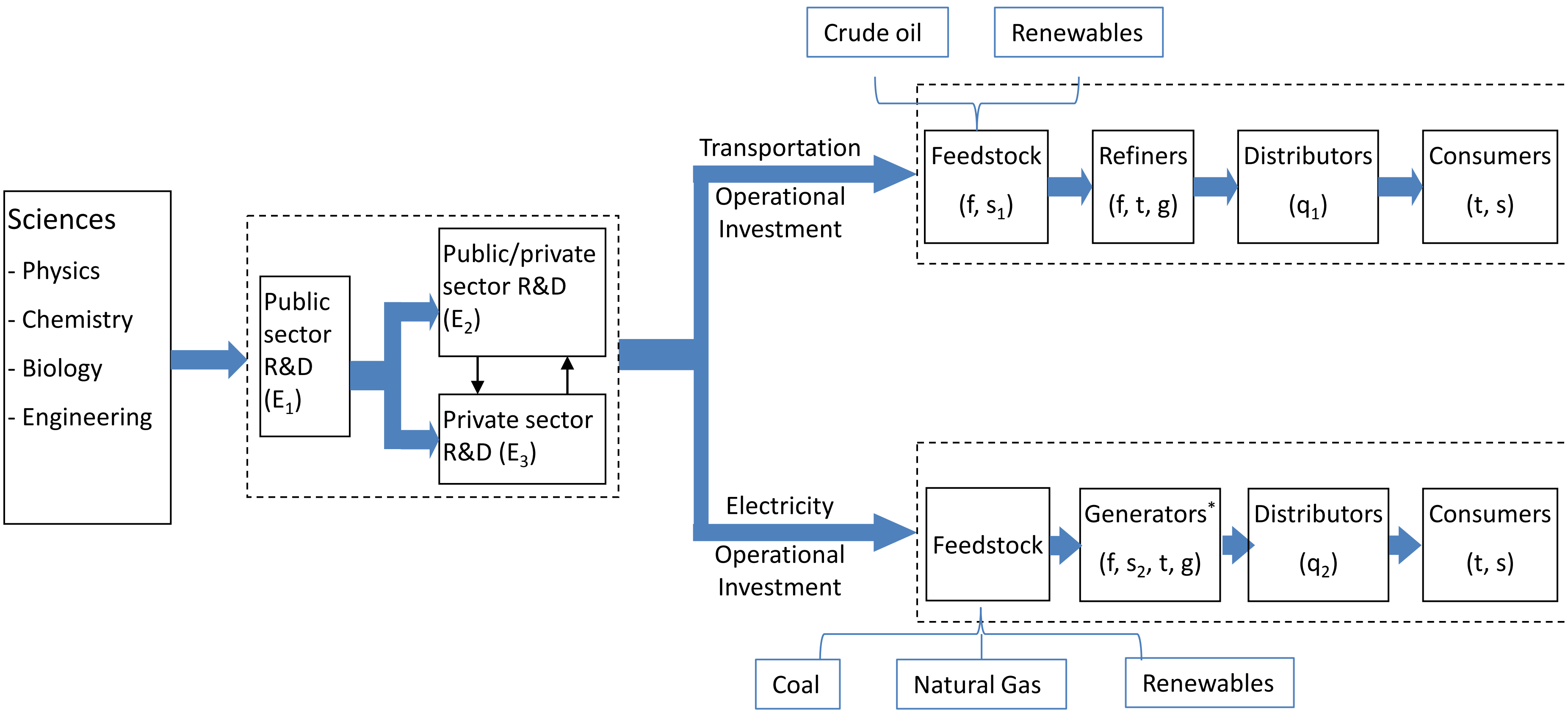
Biofuels production (1000 barrels/ day), 2011

- In a comparative assessment, the key distinguishing characteristics are:
  - The mix of policy instruments currently pursued.
  - The differences in country endowments and comparative advantage.
  - The technology emphasis by country, if any.
  - Whether the focus is on new research and development discoveries or innovation versus operational investments to capture economies of scale or learning by doing.
  - What evidence exists on the type, if any, of knowledge spillovers

Country endowment comparative advantage

- Close to northern Atlantic, Europe is rich in wind energy, especially off-shore wind power
- Solar energy is abundant in China, United States, India, and Brazil which are located in middle latitude areas
- Brazil is the largest sugarcane producer accounting for more than 40% of the world production in 2010.
- US is the largest maize producer accounting for nearly 40% of the world production in 2010.
- German and France are the fourth and the fifth largest canola producer in 2010.

Vertical Structure: Two Channels



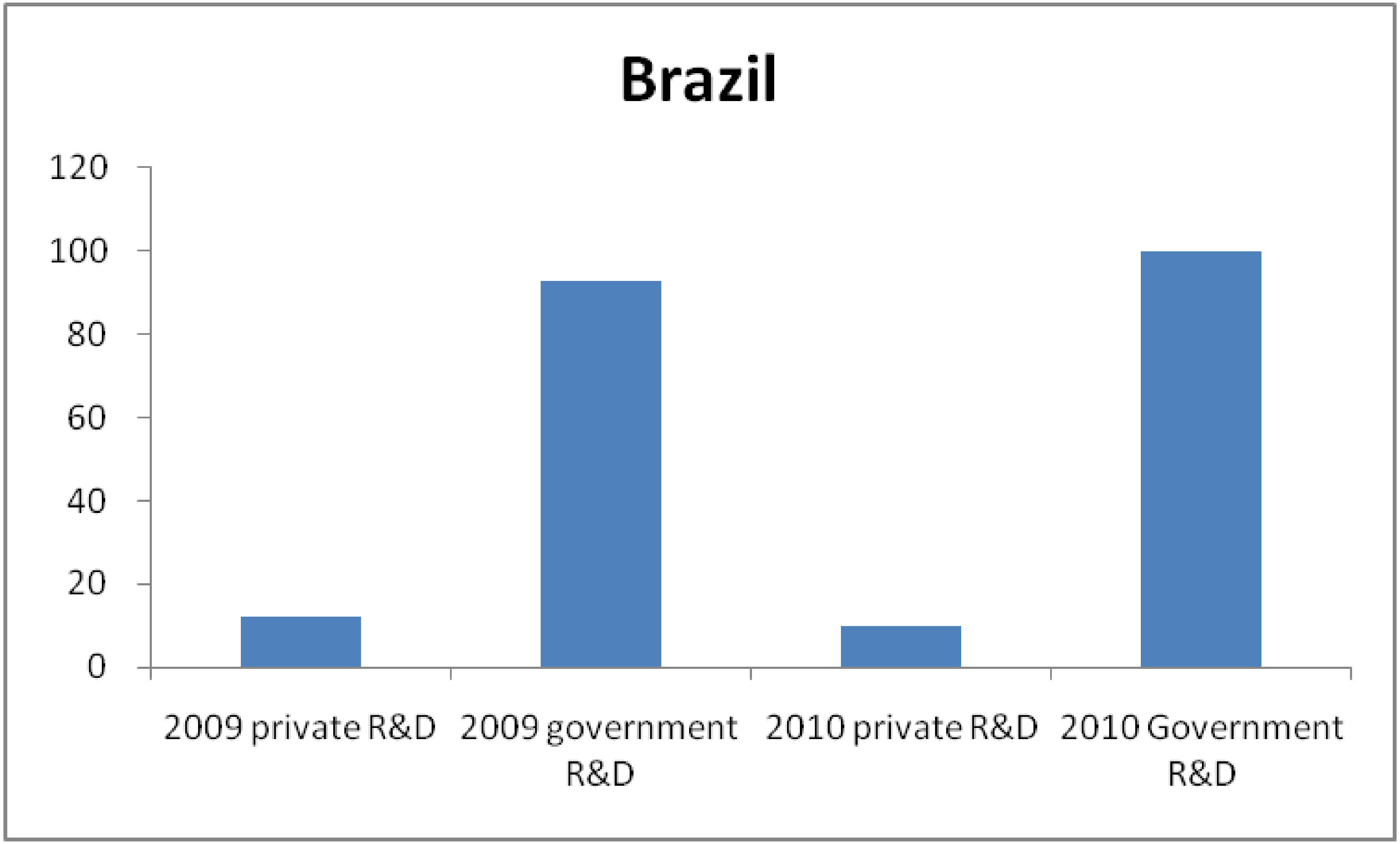
Generators include independent power plants, vertically integrated power plants and consumers who generate renewable energy themselves.

- Five categories of policy instruments
  - Public sector R&D expenditures
    - Public sector R&D expenditures (E_1)
    - Public-private sector R&D subsidies (E_2)
    - Subsidies for private sector R&D (E_3)
  - Market-based incentives
    - Quantity or output mandates. (In the case of electricity, renewable portfolio standards and in the case of biofuels, renewable volumetric obligations ($q_{1,}$ q_2))
    - Price subsidies. (In the case of electricity, feed-in tariffs or feed-in premiums (s_1, s_2))
  - Externality-based incentives. (Carbon taxes, cap-and-trade: see Goulder and Mathai, Fisher and Newell, Schneider and Goulder, Acemoglue et al.) (g)
  - Financial instruments. (Debt capital distortions reflected by low-cost loans, grants, loan guarantees) (f)
  - Tax-based policy instruments. (Performance-based tax reductions, e.g., VAT credits, fuel tax exemptions, investment tax credits, accelerated depreciation) (t)

Mix of policy instruments – Brazil

- Downstream incentives (q_1, t, s_1, f) have been used to promote sugarcane ethanol—for transport sector
  - Ethanol-use mandates (20-25 percent in gasoline)
  - Tax credits to refiners
  - Direct subsidies to small growers in North-Northeast region for sugarcane production
  - BRL 30 billion (~ USD 19 billion) credit lines to fund renewable energy investment
- Market-based measures (s_2) have been used to promote renewable electricity—for electricity sector
  - The National Programme for Energy Development of States and Municipalities (PRODEEM) was set up in 1996 to develop 20,000 MW of renewable electricity.
  - 21 million Reals were funded solar PV between 1996-2000
  - 60 million Reals were funded solar PV in 2001.

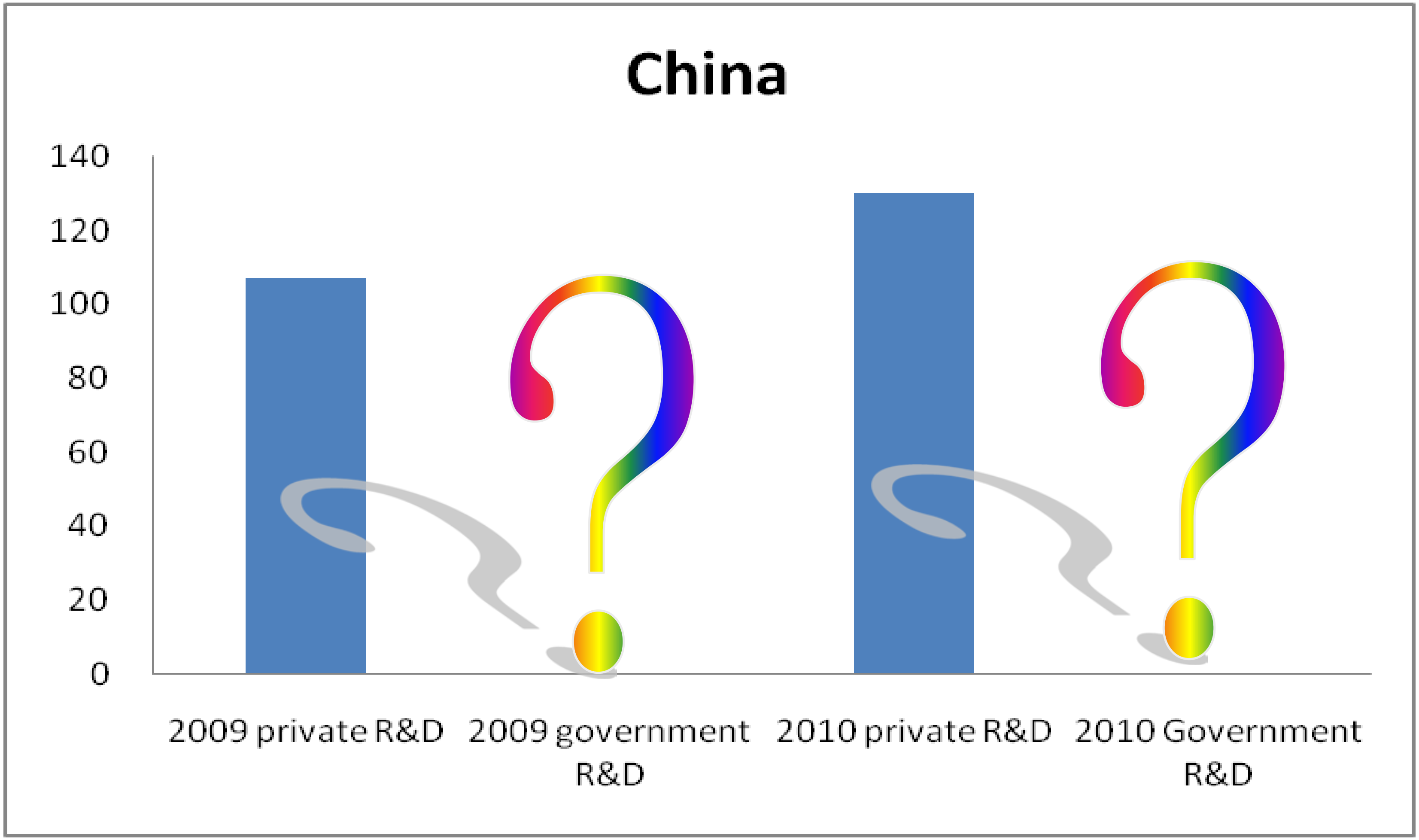
Upstream R&D investment: Government vs. Private ($M)



Mix of policy instruments – China

- Upstream R&D investment (E) has been made in wind and solar technology
  - In 2009, CNY 25.0 billion (~ USD 3.7 million) was invested
- Downstream policy instruments ($s_{2,}$ q_2) have been used to promote renewable electricity
  - Price subsidies for wind power, biomass electricity
  - Mandatory purchase of all electricity from renewable energy
- China has largely avoided fuel ethanol because of the concern about food security

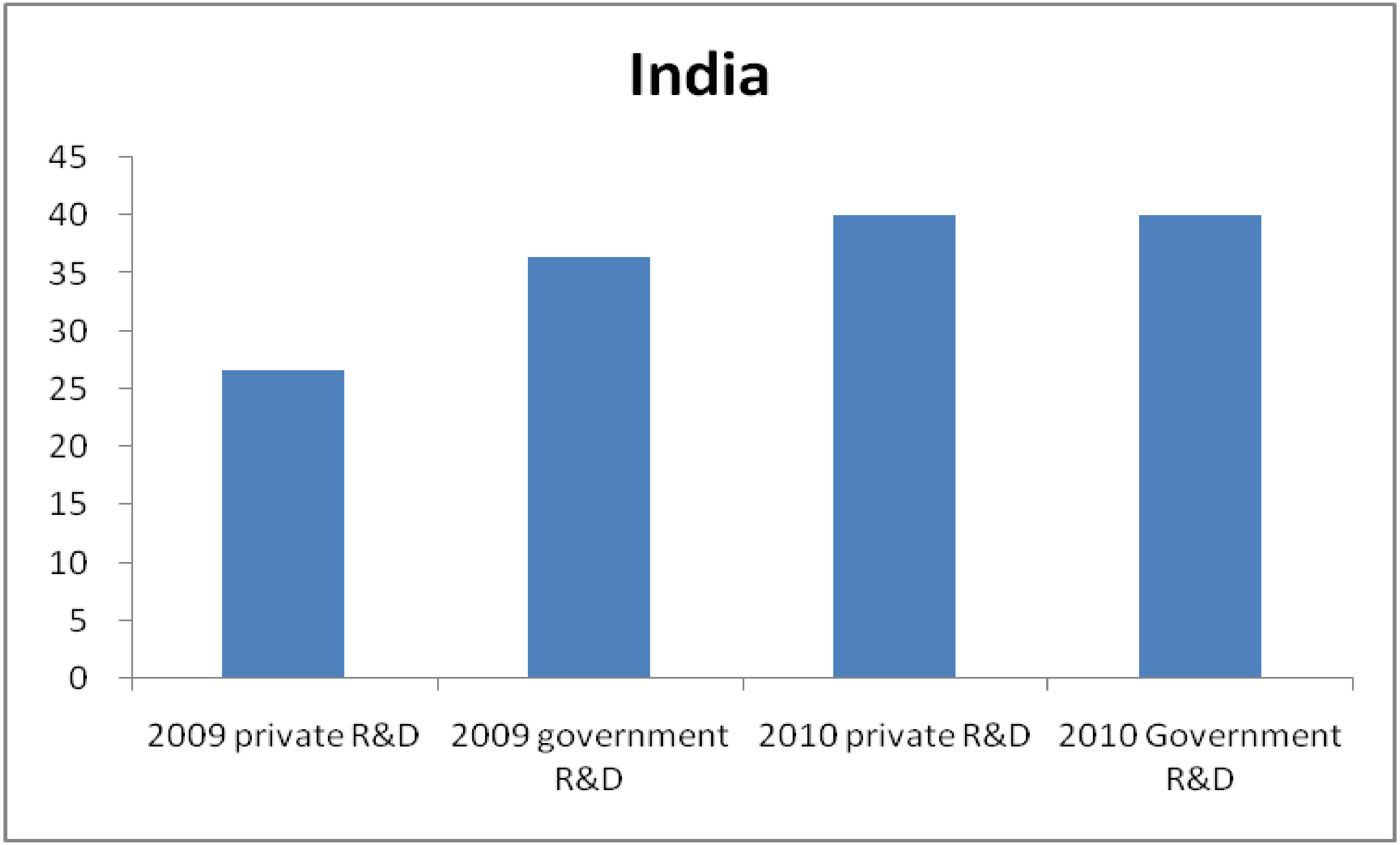
Upstream R&D investment: Government vs. Private ($M)



Mix of policy instruments – India

- Market-based, tax-based and financial instruments have been used to promote renewable electricity (q_1, s_2)
  - Mandatory share of renewable electricity in total electricity energy (10% in 2015)
  - Price subsidies for wind power, solar energy
  - Tax-based policies for wind and hydropower
  - Financial instruments for biogas
- Market-based measures have been taken to improve fuel ethanol (s_2, q_1)
  - Paying a uniform price of USD 0.54 per liter for ethanol (2007)
  - Mandatory blending of ethanol in petrol (10%, 2008)

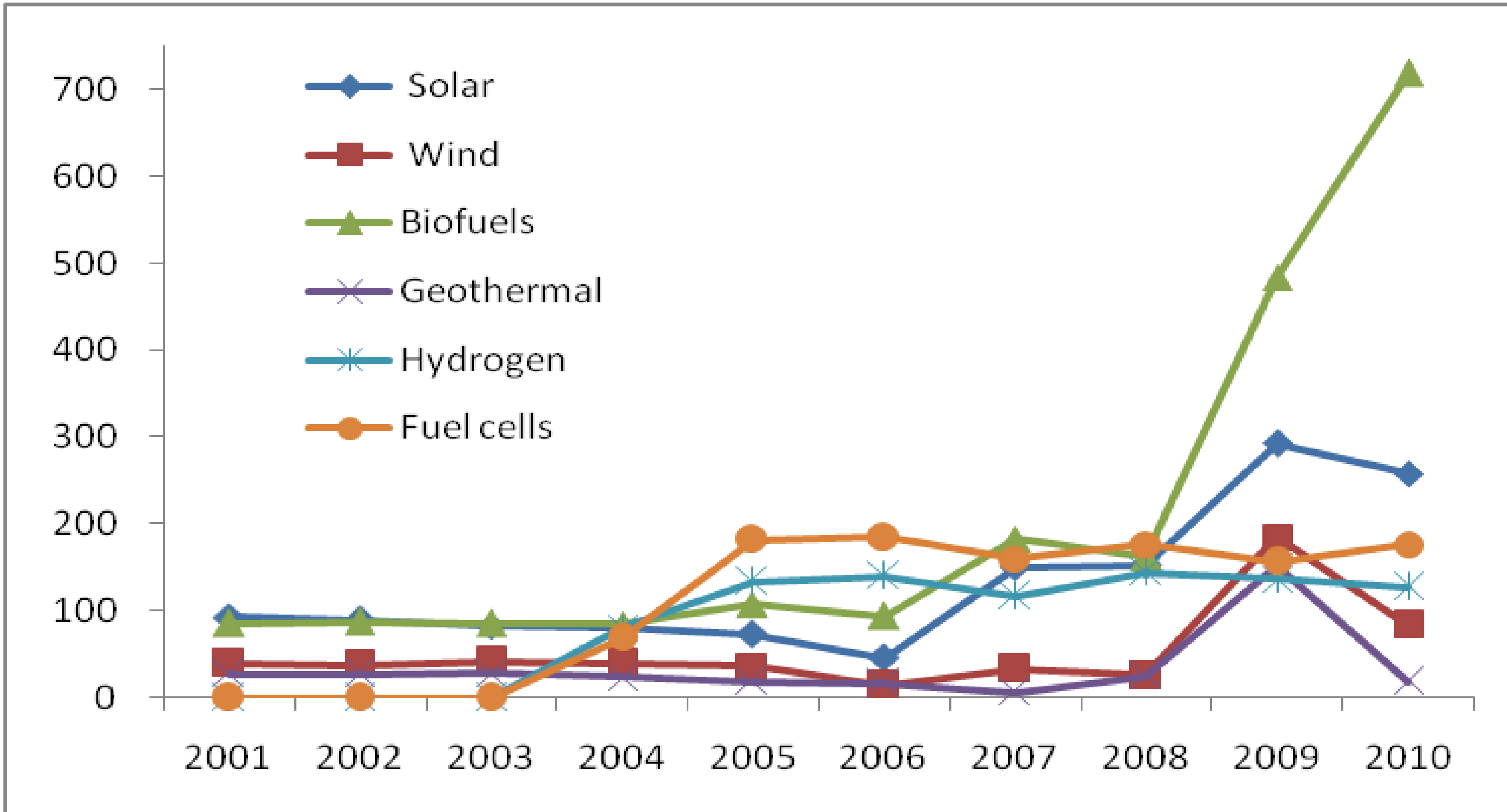
Upstream R&D investment: Government vs. Private ($M)



Mix of policy instruments – US

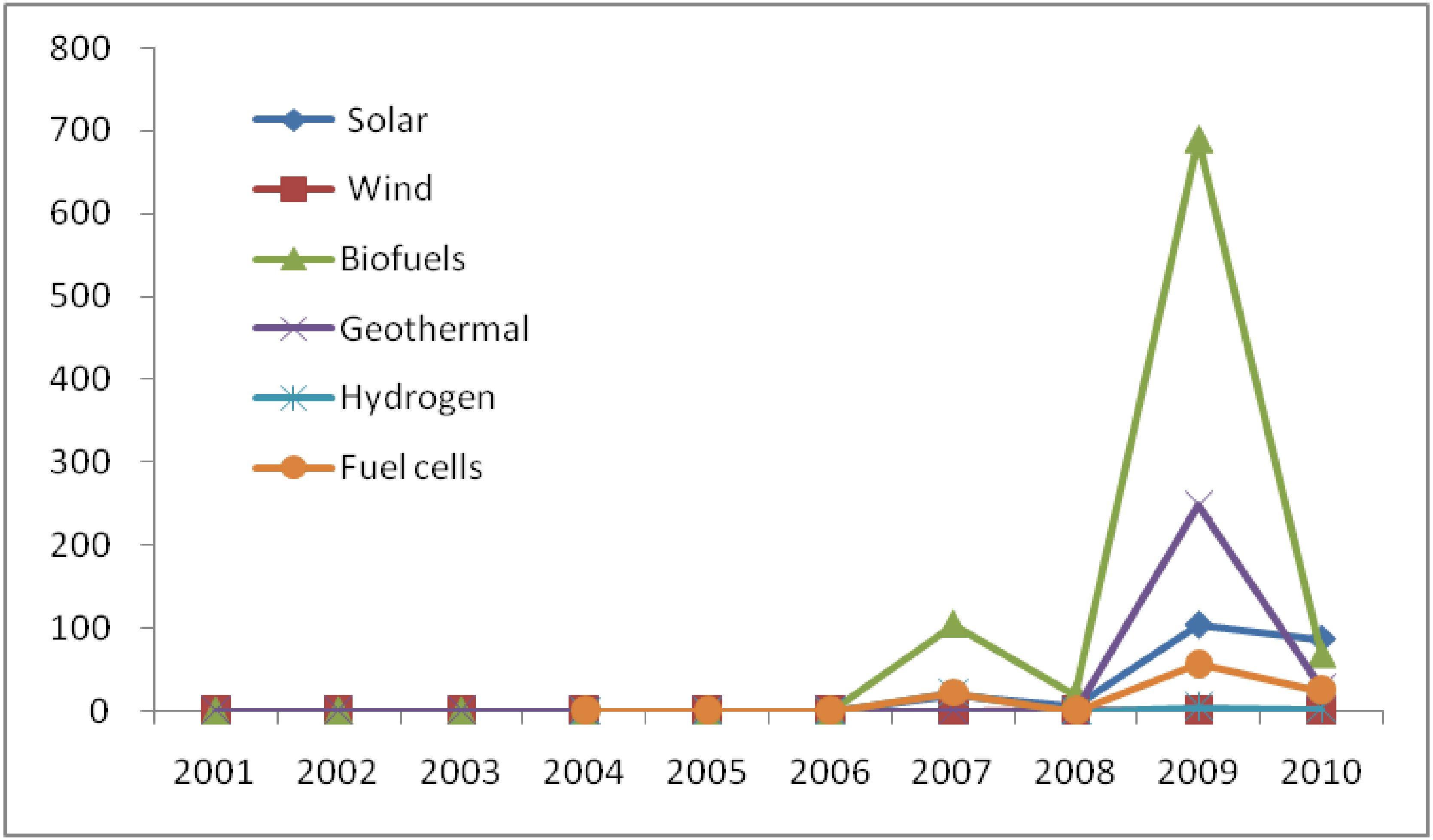
- Downstream measures (t, f, s_2)have been used to promote renewable electricity
  - Tax credit for investment and production
  - Loan guarantees
  - Production subsidy
- Downstream measures (t, f, q_1) have been used to promote biofuel
  - Tax exemptions for biofuel refiners
  - Loan guarantees
  - Renewable Volume Obligation (RVO) on gasoline producers

Government Renewable Energy R&D investment



Selected Technologies (nominal, $M)

Private Renewable Energy R&D investment



Selected Technologies (nominal, $M)

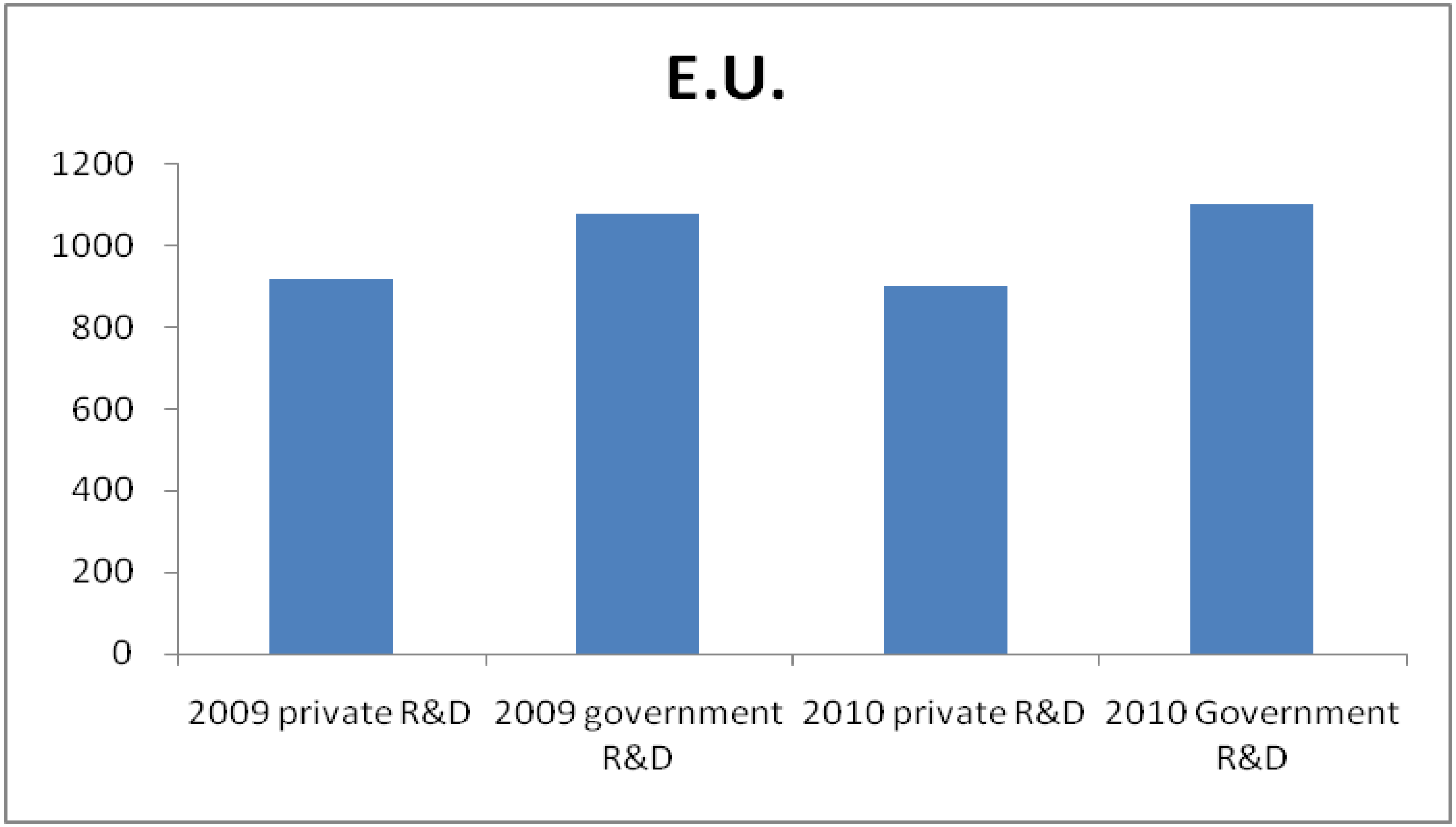
Mix of policy instruments – EU

- Upstream R&D investment has been made in solar, wind and biofuels.
  - Under FP7, EUR 2.35 bn investment focus on hydrogen and fuel cells, renewable electricity generation, renewable fuel production, renewable for heating and cooling and other clean and smart energy research.
- Externality-based incentives (g) have been used to reduce the fossil fuel consumption
  - Emissions Trading System (ETS) at EU level
  - Carbon taxes in seven member states

Mix of policy instruments – EU

- Downstream measures (s_2, f, t) have been used to promote renewable electricity,
  - Preferential prices
  - Investment grants
  - Tax incentives
- Downstream measures (q_1, t) have been used to promote renewable electricity,
  - Quota obligations on distributors
  - Tax incentives for refiners

Upstream R&D investment: Government vs. Private ($M)



- EU is the largest player in renewable energy R&D with more than $2,000 million in 2010

Technology emphasis by country

- Brazil – Biofuel, biomass and waste
- China – Wind, solar
- EU – Wind, solar, biofuel, biomass and waste
- India – Wind and biogas
- US – Solar, wind, biofuel, biomass and waste

R&D discoveries vs. operational learning by doing emphasis

- US – R&D innovation
- EU – R&D innovation
- Brazil – Operational learning by doing
- China – Operational learning by doing
- India – Operational learning by doing

3. Literature Highlights

- Key components of knowledge spillover probabilities (Harrison and Rodriguez-Clare 2009)
  - Isolate Marshallian externalities: local externalities that increase with the size of the industry and arise through localized industry-level knowledge spillovers, input-output linkages, and give rise to geographic agglomeration of industries
  - Isolate opportunities for collective action that increases productivity. Such productivity-enhancing collective action results from the existence of coordination failures
  - Isolate potential welfare-enhancing diversification (Hausmann and Rodrik 2003). Such diversification can be linked directly to productivity as well as perhaps the pricing of vulnerabilities to the supply of fossil fuel-based energy from the Mideast or intermitted supply from alternative renewable energy technologies.

Fischer and Newell (2008)

- Key specification
  - Two sectors: fossil-fueled sector (coal, natural gas), and renewable energy sector
  - Knowledge stock is a function of
    - Cumulative knowledge from R&D, and
    - Cumulative experience through learning by doing
- Key parameters
  - Elasticities and intercepts for coal-based, natural gas, and renewable electricity supply
  - CO_2 intensity for coal, natural gas (zero for renewables)
  - Learning parameter
  - R&D parameter
  - R&D investment cost
  - Degree of appropriability

Fischer and Newell (2008)

- Policy instruments
  - Emissions price
  - Renewables technology R&D subsidy
  - Downstream incentives
    - Output tax (on fossil-fueled generation)
    - Renewable energy production subsidy
    - Tradable emissions performance standard
    - Renewable Portfolio Standard
- Objective function
  - Economic surplus
- Optimal portfolio of policy instruments
  - All of the three major policy instruments with ranking among them without any recognition of their substitutability or complementarity
- Whether renewables technology R&D subsidy and production subsidy are substitutes or complements depend on whether R&D discoveries and learning are substitutes or complements

Acemoglu, Aghion, Bursztyn, and Hemous (2012)

- Introduces growth model with directed technical change under environmental constraints
- Key specification
  - A unique final good is produced competitively from two inputs:
    - clean input
    - dirty input
  - The two inputs are produced using
    - Labor
    - A continuum of sector-specific machines
  - Successful innovation increases the quality of machines
- Key parameters
  - Elasticity of substitution between two sectors
  - Rate of degradation resulting from the production of dirty inputs
  - Rate of environmental regeneration
  - Relative levels of technology development in two sectors
  - Output elasticity of inputs production
  - Probability of success in innovation
  - Discount rate

Acemoglu, Aghion, Bursztyn, and Hemous (2012)

- Policy instruments
  - Tax on dirty input: environmental externality
  - Subsidy to clean innovation: knowledge externality
  - Subsidy for the use of all machines: underutilization of machines due to monopoly pricing
- Objective function
  - Intertemporal utility of the representative consumer
- Optimal portfolio of policy instruments
  - All of the three policy instruments
  - Optimal policy includes both carbon taxes and private sector research subsidies, with former temporary, lasting until renewables dominant
  - Under presumed parameter values, optimal to redirect technical change toward renewables which counters environmental regulations that reduce long-term growth
- Driving forces behind the substitutability between tax on dirty inputs and subsidy to clean innovation
  - Market size effect (encouraging innovation in the sector with greater employment and thus with the larger market for machines)

4. Renewable Energy Technologies

4.1 Hydrogen Breakthrough Potential

Storage Capacity

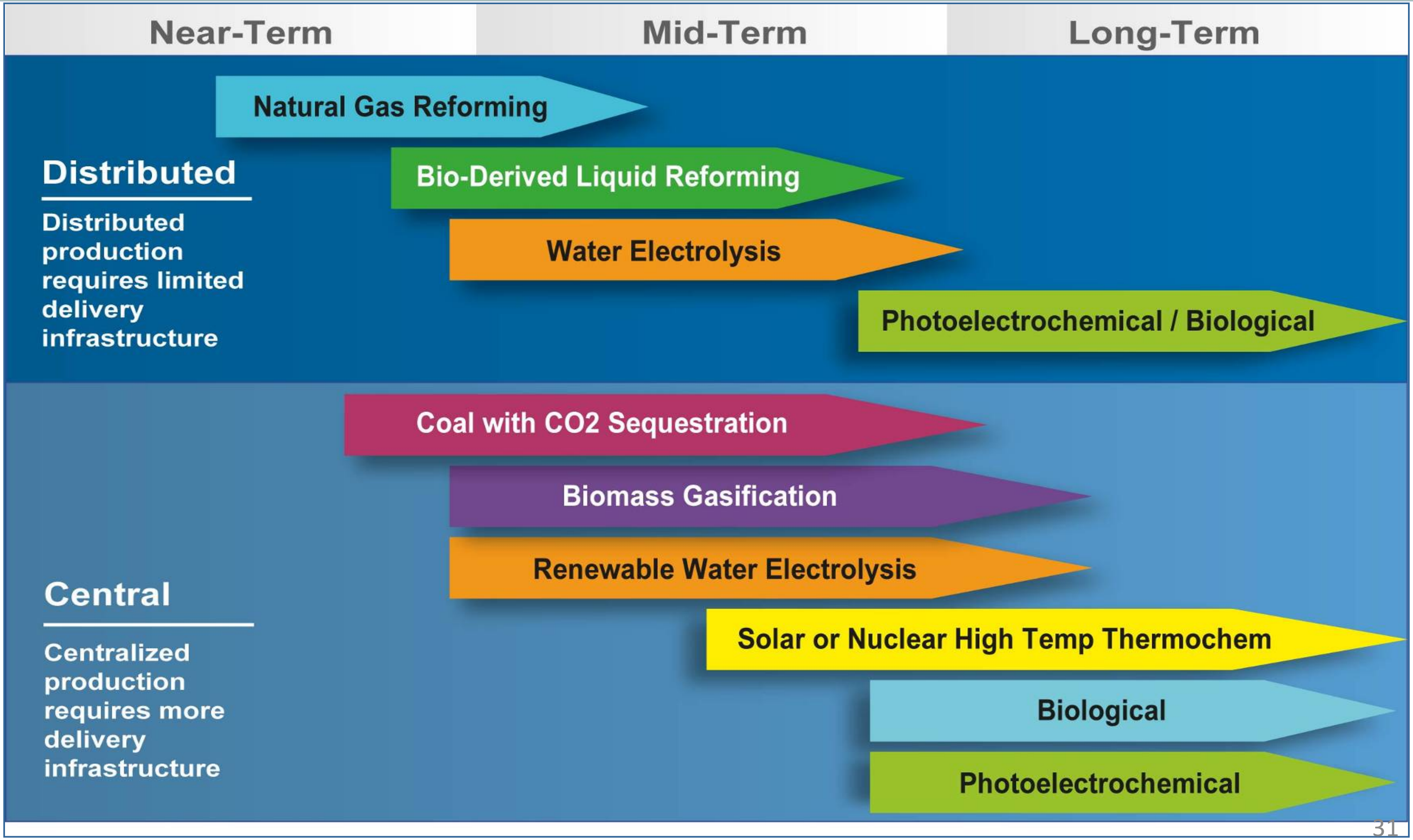
- High-density hydrogen storage
- Solid hydrogen fuel
- Hydrogen storage with carbon nanotubes
- Reduced Vehicle Weights

'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.**



4.2 Fuel Cells

- Development of cost-competitive hydrogen storage technologies is a key to potential fuel cell commercialization.
- Use of fuel cells have been developed for transport and stationary applications.
- Current R&D efforts have focused on proton exchange membrane technologies, molten carbonated fuel cells, and solid oxide fuel cells.
- Hydrocarbon fuels (natural gas, biofuels) are expected to continue to be the dominant fuel in the near- to medium-term.

Fuel Cells

- The durability of fuel cell systems has not been established and remains an R&D challenge.
- The size and weight of current fuel systems must be reduced to satisfy the packaging requirement for automobiles.
- Current thermal and water management for fuel cells necessitates commercially unacceptable large heat exchangers.
- Technologies must be developed to allow higher operating temperatures and/or more effective heat recovery systems.

4.3 Hybrid/Electric Vehicle Potential Breakthroughs

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

  -less degradation with age

4.4 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

4.5 Wind Energy Breakthroughs

Continued Incremental Turbine Improvement:

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

4.6 Biofuels: Potential Breakthrough Opportunities

Cellulosic Ethanol

-Depolymerization/Hydrolysis

-New Microbes

-New Catalysts

Feedstock Development:

-Miscanthus

-Switchgrass

-Wood

-Agricultural Waste

Biodiesel

-Cellulosic Biomass

-Algae

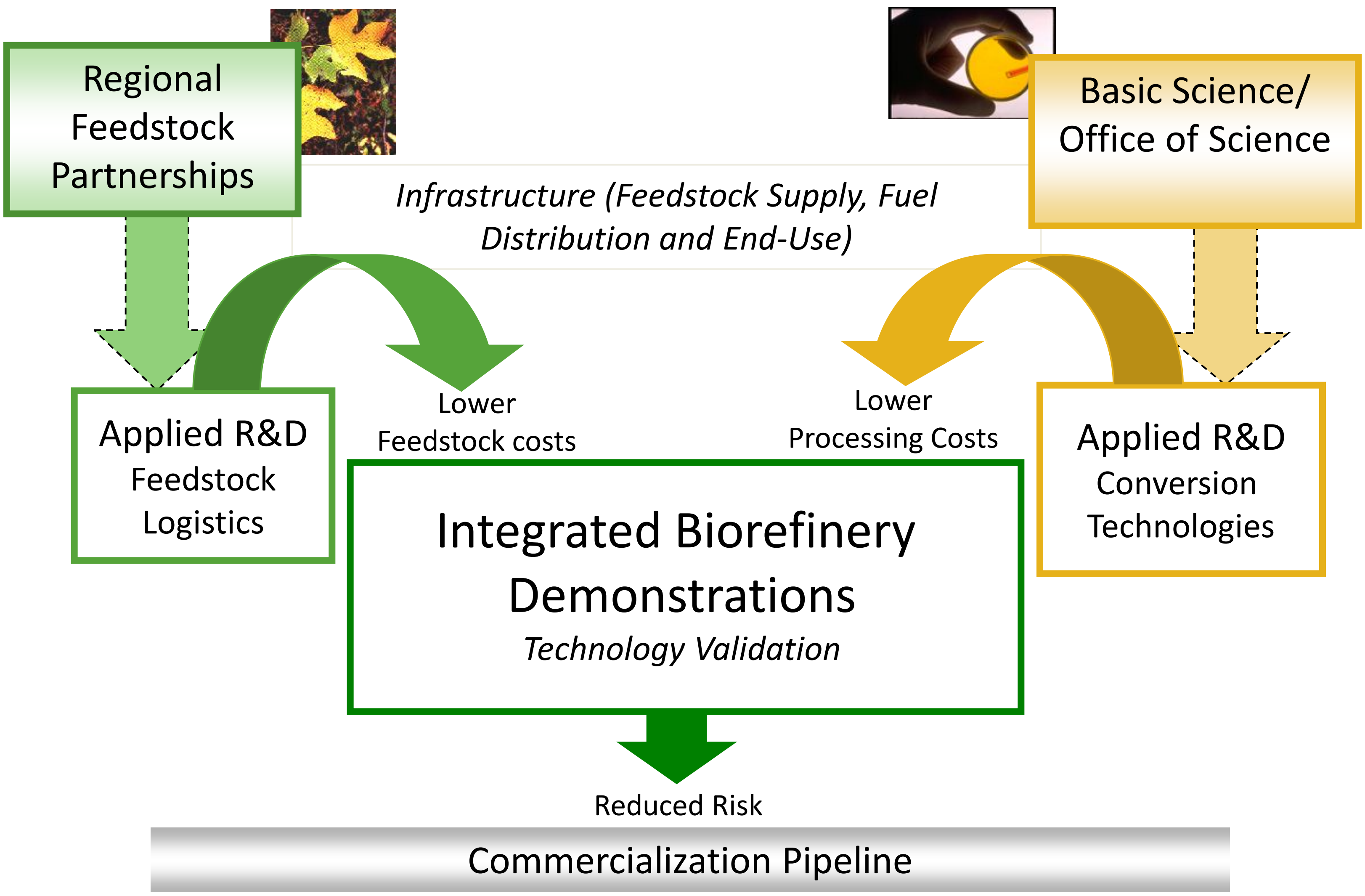
-Waste

Conventional Ethanol

-Corn Seed Genetics

-New Enzymes

Strategic Approach



Range of Possible Biorefinery Concepts

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

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

Products

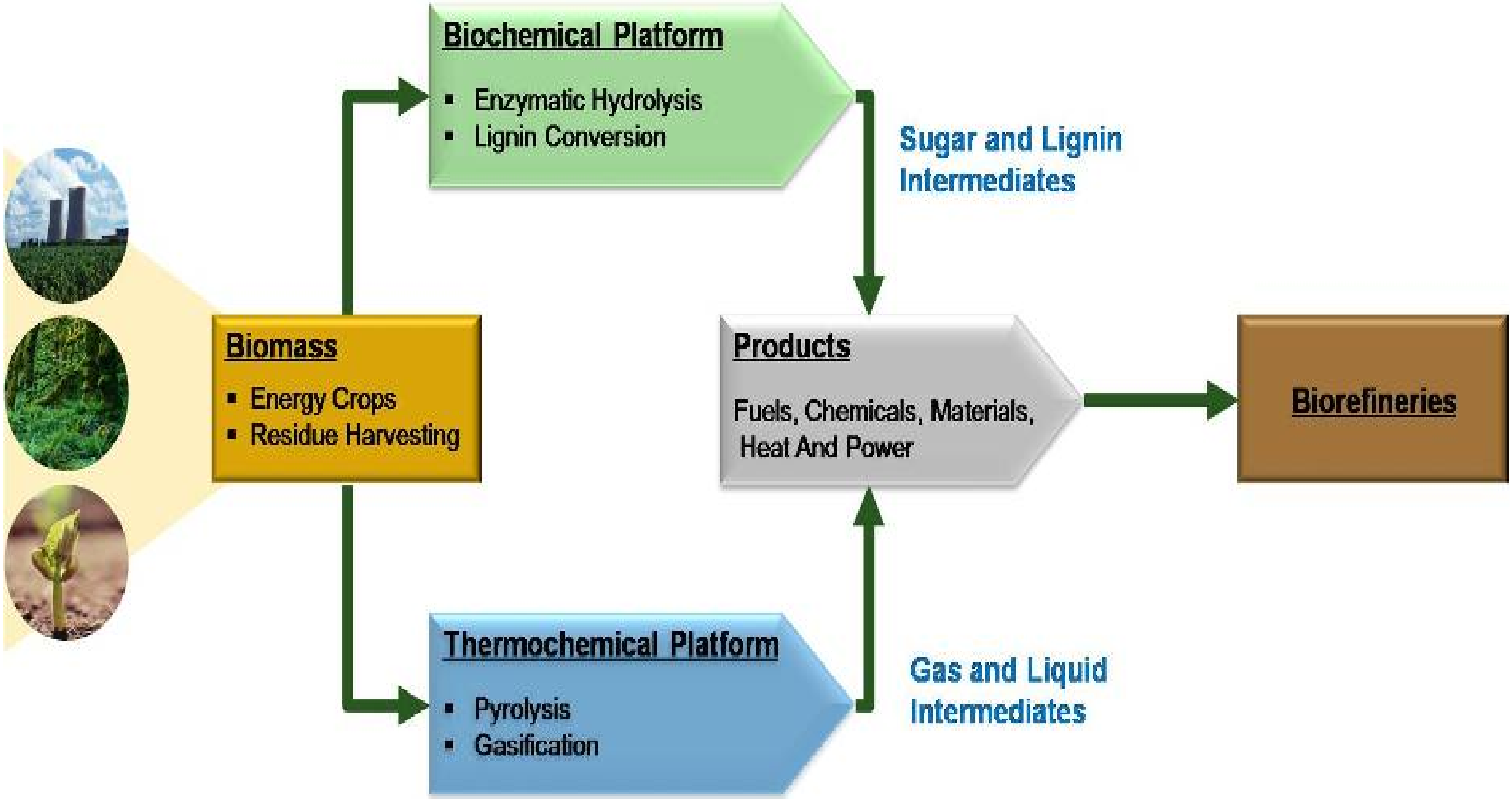
Fuels
- Ethanol
- Biodiesel
- "Green" Gasoline & Diesel

Power
- Electricity
- Heat

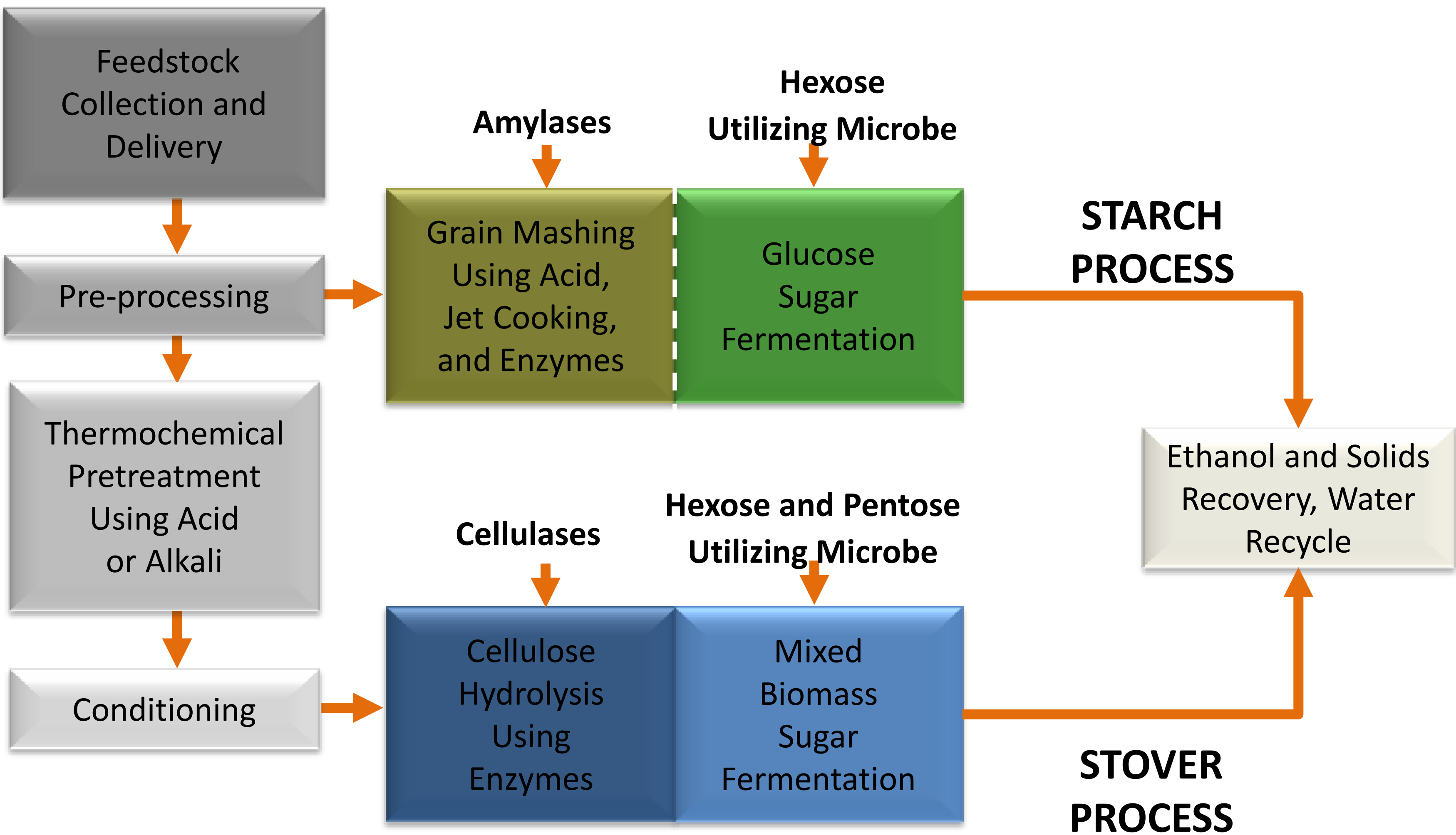
Chemicals
- Plastics
- Solvents
- Chemical Intermediates
- Phenolics
- Adhesives
- Furfural
- Fatty Acids
- Acetic Acid
- Carbon Black
- Paints
- Dyes, Pigments, and Ink
- Detergents
- Etc.

Food and Feed

Alternative Paths to Biofuel Production



The Biofuel Production Process



4.7 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

5. What is missing from the current public discourse and academic research?

- No complete integrated assessment including all the relevant dimensions of public policy analysis
  - Incidence: Who wins, and who loses
  - Mechanism Design: Implementation, hidden information, hidden actions, and strategy-proof
  - Political Economy: Formation of interest groups and the resulting tradeoff between the public and specialized interests (e.g., US ethanol industry)
  - Governance Structures: Assigned authority, accountability, admissible coalitions

- No academic research or public discourse on the potential complementarities among policy instruments across the alternative renewable energy technologies
  - Academic research has identified and quantified the complementarities across upstream R&D investments and market-based incentives
  - No evidence on the potential role of supermodularity in the development of a renewable energy industry
  - The incremental value of R&D expenditures increases as a result of more downstream market-based incentives
  - Market dynamics of future substitutability with natural gas

- The principal uncertainties include:
  - Innovation or discovery (cost parameter reductions) resulting from R&D expenditures by technology
  - Economies of scale parameters by technology
  - Learning by doing parameters by technology
  - Knowledge spillover parameters by technology
  - Willingness to pay for renewable (“clean”) versus fossil (“dirty”) energy by final consumers
  - Degree of private sector appropriability R&D investments by technology
  - Whether any renewable energy technology will ever be commercially viable, given the technological advances in the discoveries of vast quantities of fossil energy resources, particularly natural gas

- Failure to recognize the inherent **dual control** of current industrialization policies
  - Not only must policy instruments be set but also measurement controls
  - Both generic types, policies and measurement controls, must be jointly determined
  - There is a large array of highly uncertain parameters, whose probability distributions can be more precisely estimated through measurement controls
  - Such measurement controls will help gauge the success or failure of industrialization policies

- What is the optimal combination of upstream public R&D investments and downstream policy instruments for renewable energy technologies?
  - Upstream investments in renewable energy R&D fund either public research, or public/private research partnerships.
  - Downstream market incentives subsidizes renewable energy production.
  - Downstream non-market instruments (carbon taxes) create incentives for renewable energy production by pricing externalities resulting from utilization of fossil fuels but currently are not admitted by the political economic landscapes in four of five major countries.

Quantifying the innovation response to R&D research expenditures

- Select benchmark
- Determine conditional probability distributions as a function of R&D expenditures
- Implement Baysian learning model for updating prior conditional probability distributions
- Given the lack of empirical data, we have no recourse but to turn to expert elicitation (Rausser, Stevens, and Torani, 2011)

- Measurement controls
  - Experimentation to isolate probability distribution on economies of scale parameters
  - Experimentation for determining learning by doing parameters
  - Elicitation to determine probability distribution on discovery or innovation parameters as a function of R&D expenditures
  - Experimentation to isolate probability distribution on knowledge spillovers
  - Experimentation to determine consumers' relative willingness to pay

Research Questions

- From a political economy perspective:
  - What are the possible outcomes for politically feasible policy instruments without the imposition of carbon tax?
  - For such policy instrument regimes, how much benefit can be attributed to 1)complementarities between upstream R&D investment and downstream market-based incentives, 2) learning by doing, 3) Marshallian externalities, 4) new discoveries, and 5) differential consumers' willingness to pay for fossil-fueled energy and renewable energy ?
  - How different will a political economy framework be to a social welfare analysis presented by Fischer and Newell (2008) and Acemoglu et al. (2012)?

Simulation

- Three sources of feedstock: coal, natural gas, and renewables
- Governance function for public sector
  - 3 major policy instruments: 1) renewables production subsidy, 2) subsidy for private R&D, and 3) public R&D investment
  - Objective function: weighted sum of the profits of energy producers, consumer surplus, the government budget, and emissions
- Simulation structure (Two periods presuming perfect foresight and imposing backward induction)
  - Optimal market behavior in period 2
  - Optimal policies in period 2
  - Optimal market behavior in period 1
  - Optimal policies in period 1

Simulation

- Key parameters
  - Complementarities between upstream R&D investment and downstream market-based incentives
  - Learning by doing parameter
  - Marshallian externalities
  - Rate of new discoveries
  - Willingness to pay for renewable energy

Preliminary Results: Nonstochastic Specification

- Even without carbon externality pricing, if the public sector governance function satisfies the conditions for economic efficiency (see Rausser et al. Chapter 5)
  - All stakeholders whose well-being is influenced have access and are represented in the political process
  - All organized groups' policy objective functions faithfully reflect the group members' preferences over the policy space
  - The distribution of political power is uniform across all organized interest groups
  - The reaction functions of unorganized but responsive interest groups are arguments in all government and organized interest groups objective functions
  - The separable objective function of the assigned governmental authority reflects the public interest

Preliminary Results: Nonstochastic Specification

- A Pareto-superior equilibrium can be achieved if
  - Complementarities between upstream R&D investment and downstream market-based incentives
  - Learning by doing parameter
  - Marshallian externalities
  - New discoveries
  - Willingness to pay for renewable energy

are sufficiently large with main drivers in order of importance are:

  - Final consumers' willingness to pay for clean energy
  - The rate of R&D discovery by the public sector as well as the private sector
  - The degree of complementarity between downstream market-based subsidies and public sector R&D expenditures