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Biofuels R&D and Technology Supply

Carl E. Pray
pray@aesop.rutgers.edu

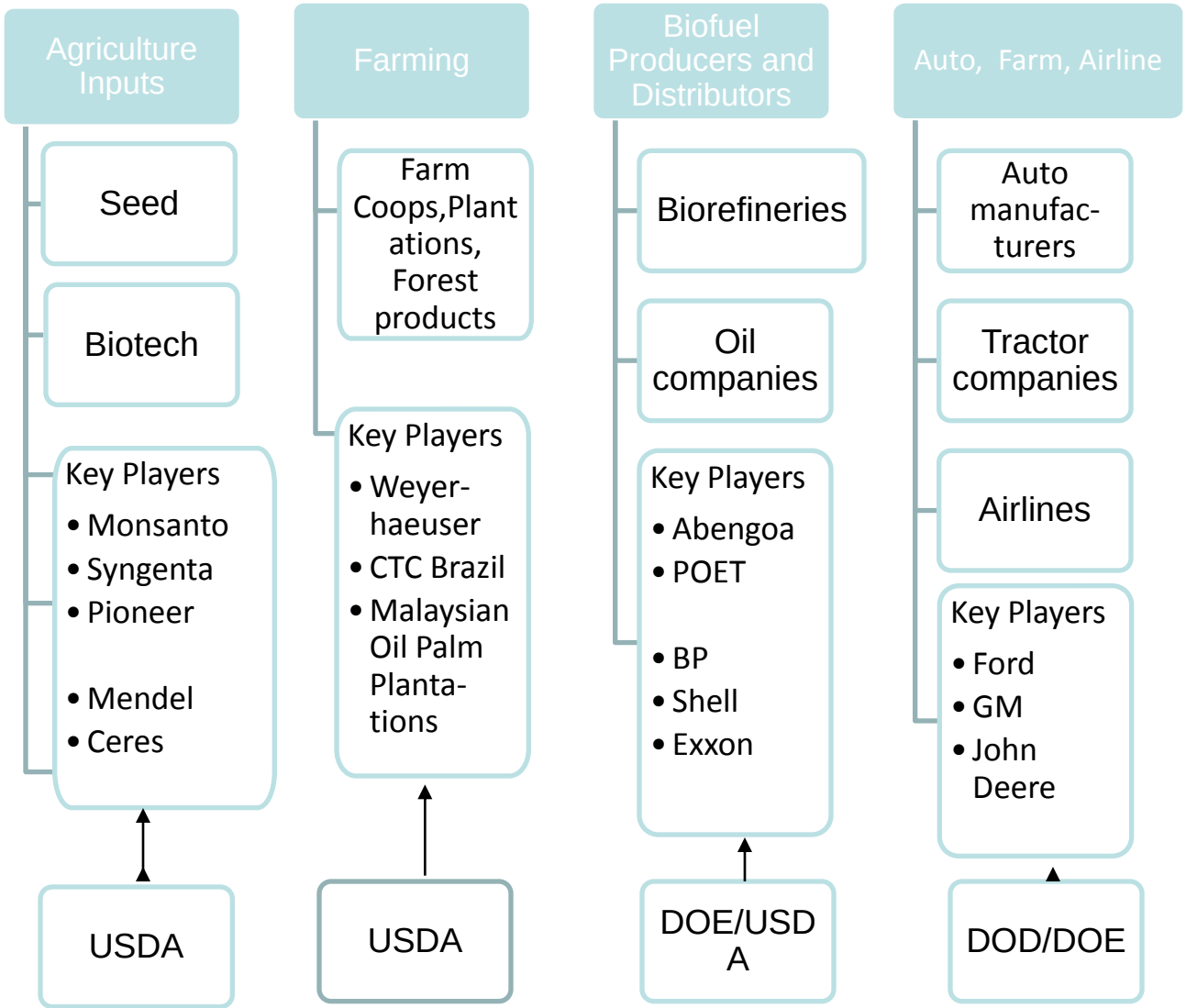
Major issues today

- How will biofuel affect the demand for agricultural products and agricultural resources?
  - First generation biofuels – demand for food
  - Second generation – cellulosic biofuels – demand for agricultural inputs and resources
    - How soon will it be competitive with first generation?
    - Where will it be produced?
  - Third generation – algae based biofuels - ? Demand for ag. resources ?
- Secondary issue for today – supply side
  - Spillover impact on productivity for food crops?
  - Impact on model's assumption about costs of food production (if sorghum or corn stalk valuable for biofuel will more grain be produced?)
- Technology transfer issues (if time)

Basis of my comments: on going study of private sector R&D and innovation

- Who is investing in biofuels research and development and how much? (So far US based with some info from India, Brazil, China and Malaysia)
- What research is being done?
  - Feedstocks
  - Conversion technologies
  - Engines
- Economic, environmental, policy drivers of R&D and innovation.
- How will biofuel technology spread international?

Biofuel supply chain & biofuel R&D

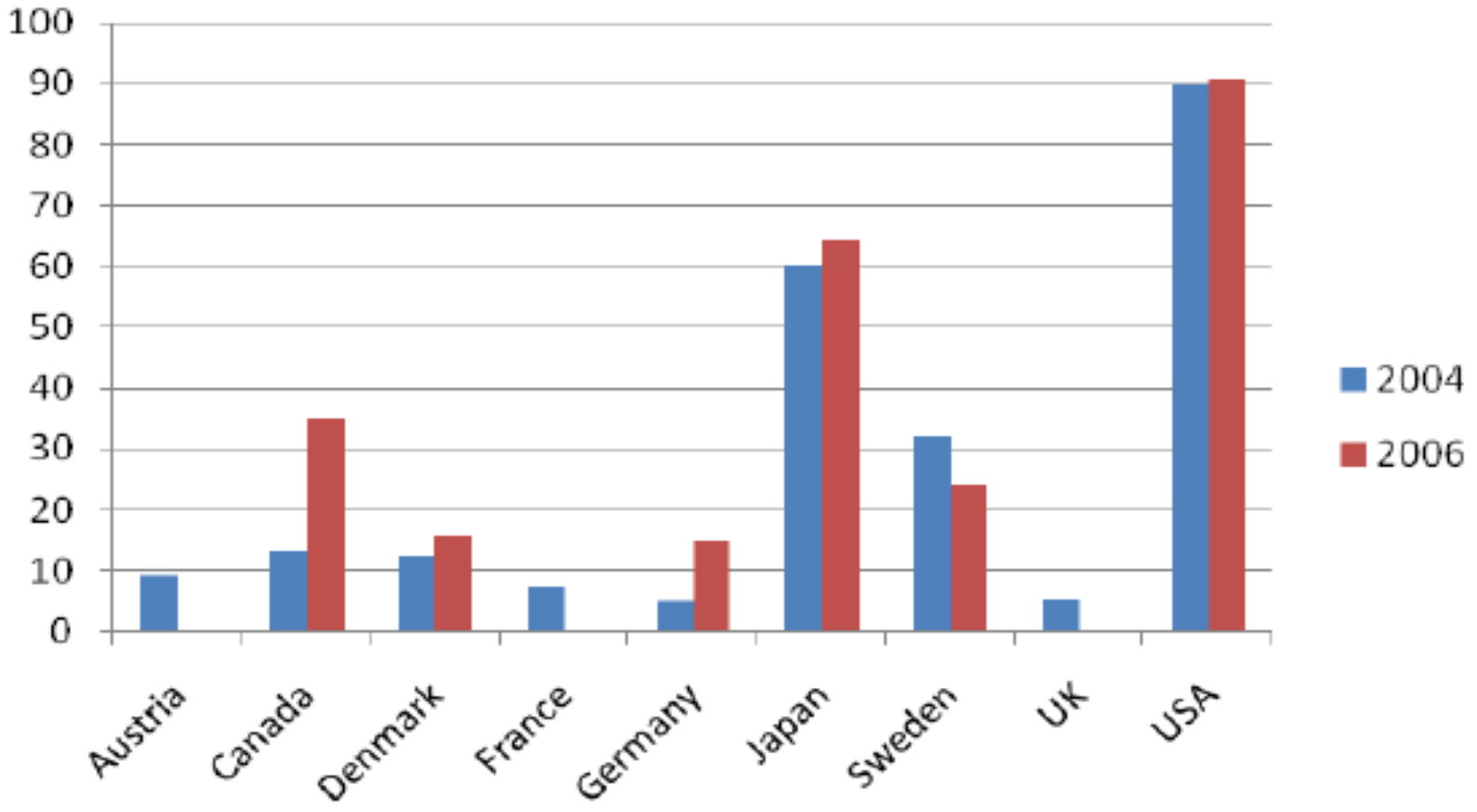


Who is doing biofuel research and development?

- Private sector worldwide – my guess?
  - At least $1 billion/year – could be $2 billion
    - From almost nothing in 2000
    - Half of this is by oil industry focusing on cellulosic biofuel and algae
    - 20%???by seed/ag biotech on feedstock
  - For comparison total seed/biotech private R&D about $2.8 billion

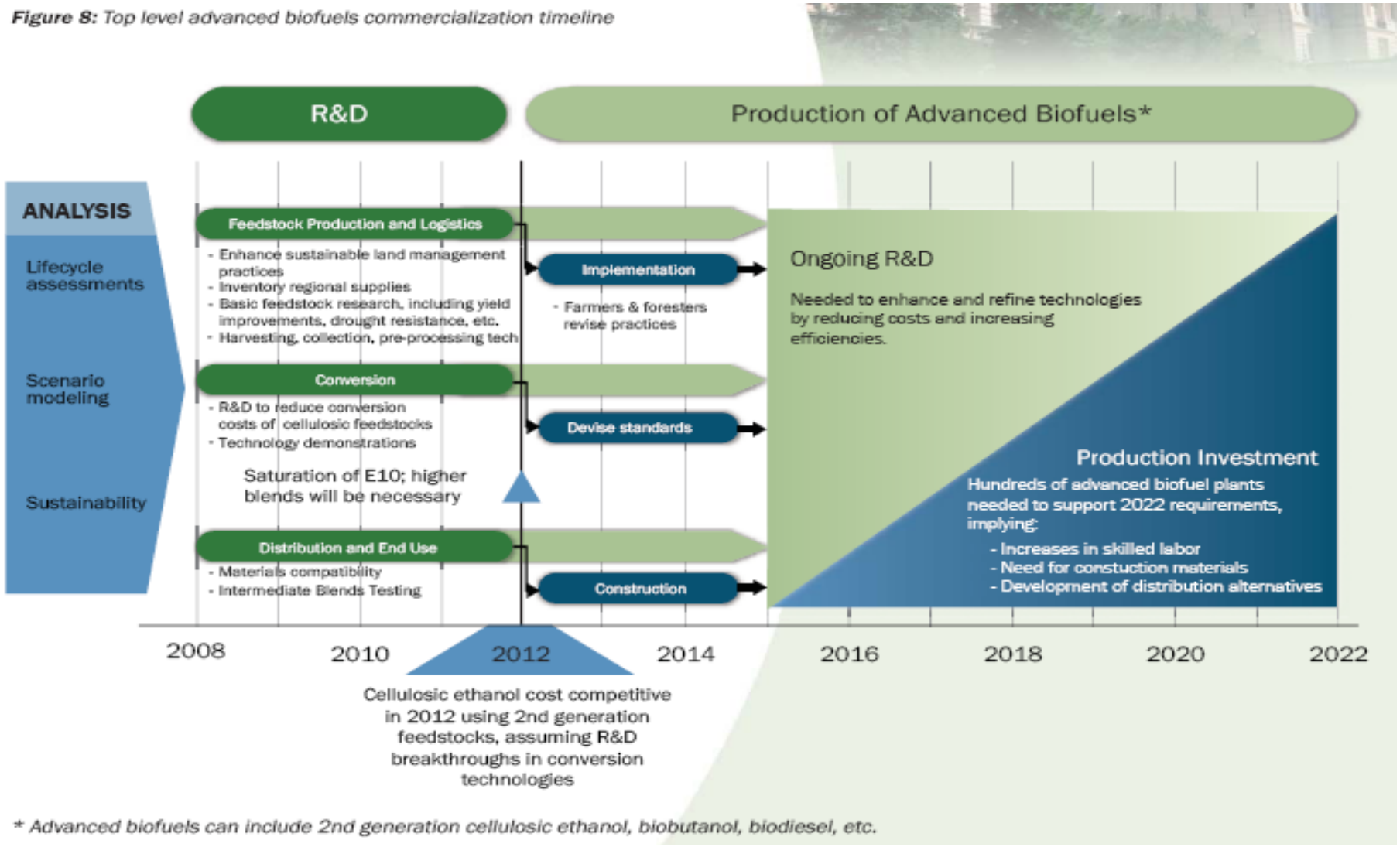
- Public sector funding
  - US – DOE + USDA was about $90 mil/year in 2007. Now committing $200 million annually
    - mainly focused on cellulosic biofuel
    - 20% feedstock productivity and management
    - 30% conversion technologies
    - 50% pilot plants and optimizing supply chain management…

Figure 1.10. Total public R&D expenditures for bioenergy, 2004-2006 (USD million)



- OECD 2008

US Government plan for research and production of 2nd generation biofuel



Major Seed/Biotech companies R&D

- All Major Companies breeding for corn yields and grain with high ethanol yields
- Syngenta
  - Developed transgenic corn with built-in enzymes to reduce cost of producing ethanol
  - Collaboration with Australian university on sugarcane for use in biofuel
- Monsanto
  - Part owner of Mendel biotech and Ceres for grasses
  - Invested $290 million in 2008 in Brazilian sugarcane breeding and biotech companies
- Pioneer/DuPont joint venture with BP
- BASF announced collaboration with CTC to improve sugarcane production

Farms and forestry companies

- Weyerhaeuser (forest products) funds biofuel research at universities and JV with Chevron
- Sugarcane producers and sugarmills fund Centro de Tecnologia Canavieira (CTC) in Brazil
- Plantation companies in Indonesia and Malaysia fund biodiesel from Oilpalm in SEAsia.

Smaller biotech/enzyme companies

- Feedstock
  - Cellulosic – Mendel, Ceres,
  - Algae – Solazyme, Algenol, Sapphire, Synthetic genomics…
- Enzymes for conversion of cellulose to sugars
  - Novozymes, Genecor, Verenium, DSM
- Yeast & other micro-organism to convert sugars and cellulose to butanol, industrial chemicals, etc.
  - Amyris
  - Many others….

Ethanol producers & equipment engineerin firms

- Two types of research
  - Thermal, chemicals, mechanical conversion
  - Systems optimization
- POET
- Mascoma – Marathon oil
- ADM – JV with Conoco/Phillips
    - JV with Wilmar International in SEAsia
- Cargill - Monsanto

Oil Companies

- BP – in house research, public private partnerships, joint ventures (Case study)
- Shell –
  - 4 in house biofuel labs US, UK, Netherlands, India and 6 collaborations with university and government research programs in the US, UK, China and Brazil
- Exxon – 2009 $600 million over 5 years for development of algae based biofuel
  - Half in-house, half to Synthetic Genomics
- Chevron, Conoco/Phillips, Marathon oil
- National companies also investing – Petrobras investing in ethanol Brazil, Petronas investing in biodiesel Malaysia

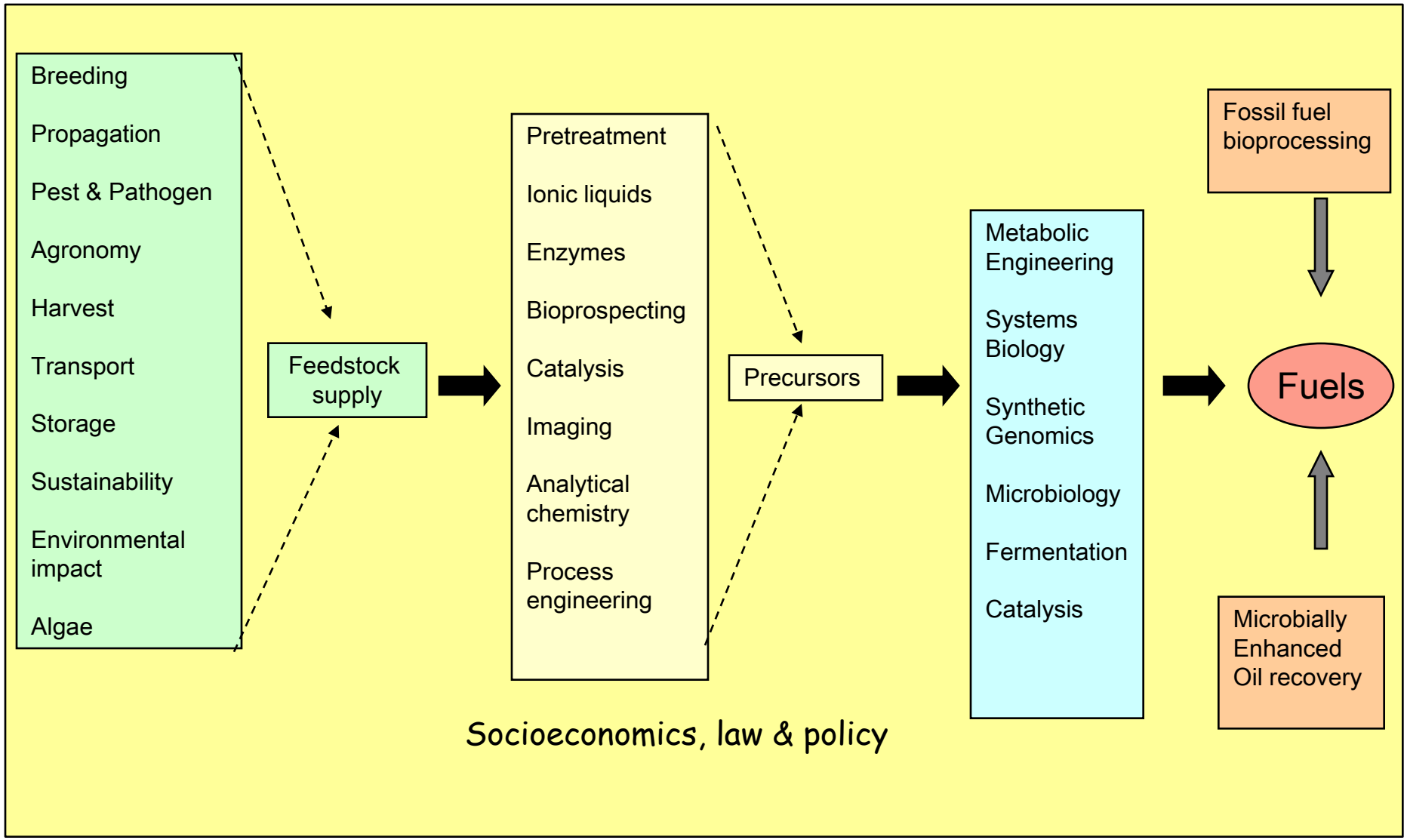
Cars, Tractors, Trains, Planes

- Cars – all major manufacturers
- Tractors – John Deere, Mahindra & Mahindra
- Trains – Virgin group
- Planes – General electric, Boeing, Virgin Atlantic, Continental and others.

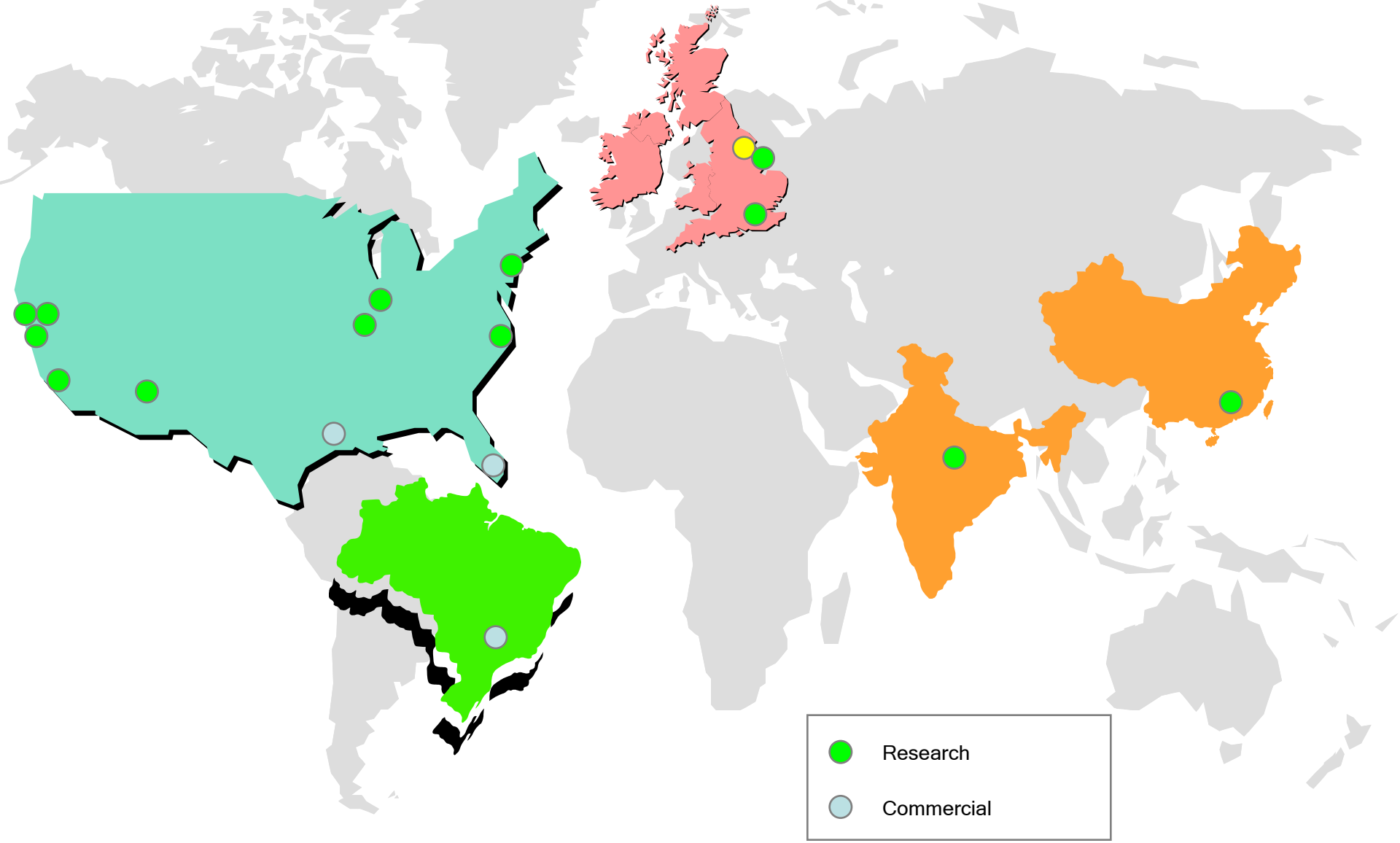
BP case study

- Major inhouse research program-size is secret
- $50 mil/year for 10 years to Energy Biosciences Institute (EBI) at Berkeley
  - R&D partnership between BP, U.C. Berkeley, Livermore labs (DOE), and U. of Illinois
- BP invested money in R&D on many feedstocks
  - Mendel(grasses – especially Miscanthus) DuPont (butanol from crops & crop waste)
  - D-1 Oils in India and Africa and The Energy Research Institute (TERI), India (jatropha),
  - Martek (algae)
- Major investments in cellulosic ethanol production
  - Florida $300 mil – ethanol production from energycane and energy grasses
  - Brazil $1 bil in ethanol & electricity production from Sugarcane

Technical reach of the EBI

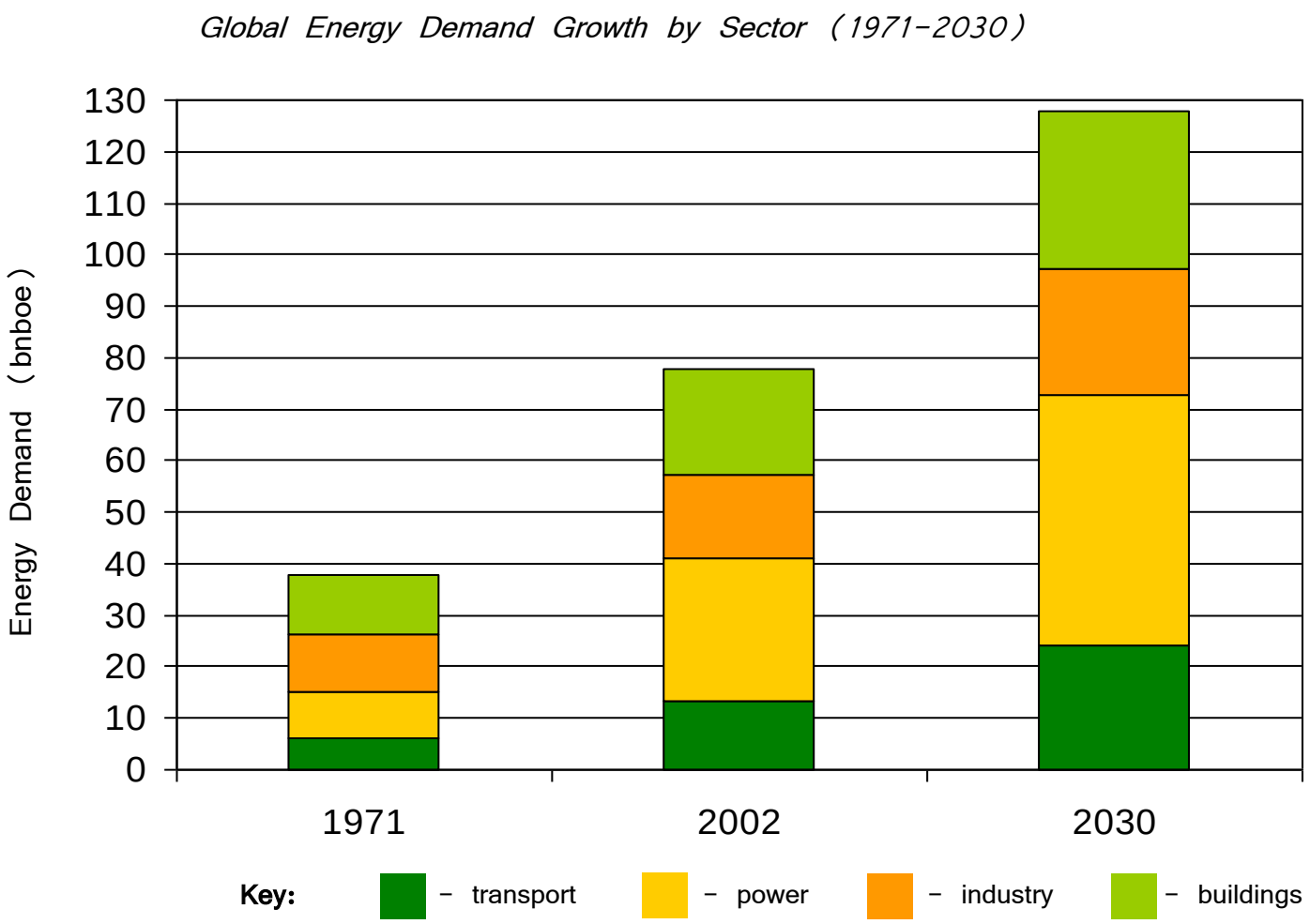


Places : BP and Collaborators



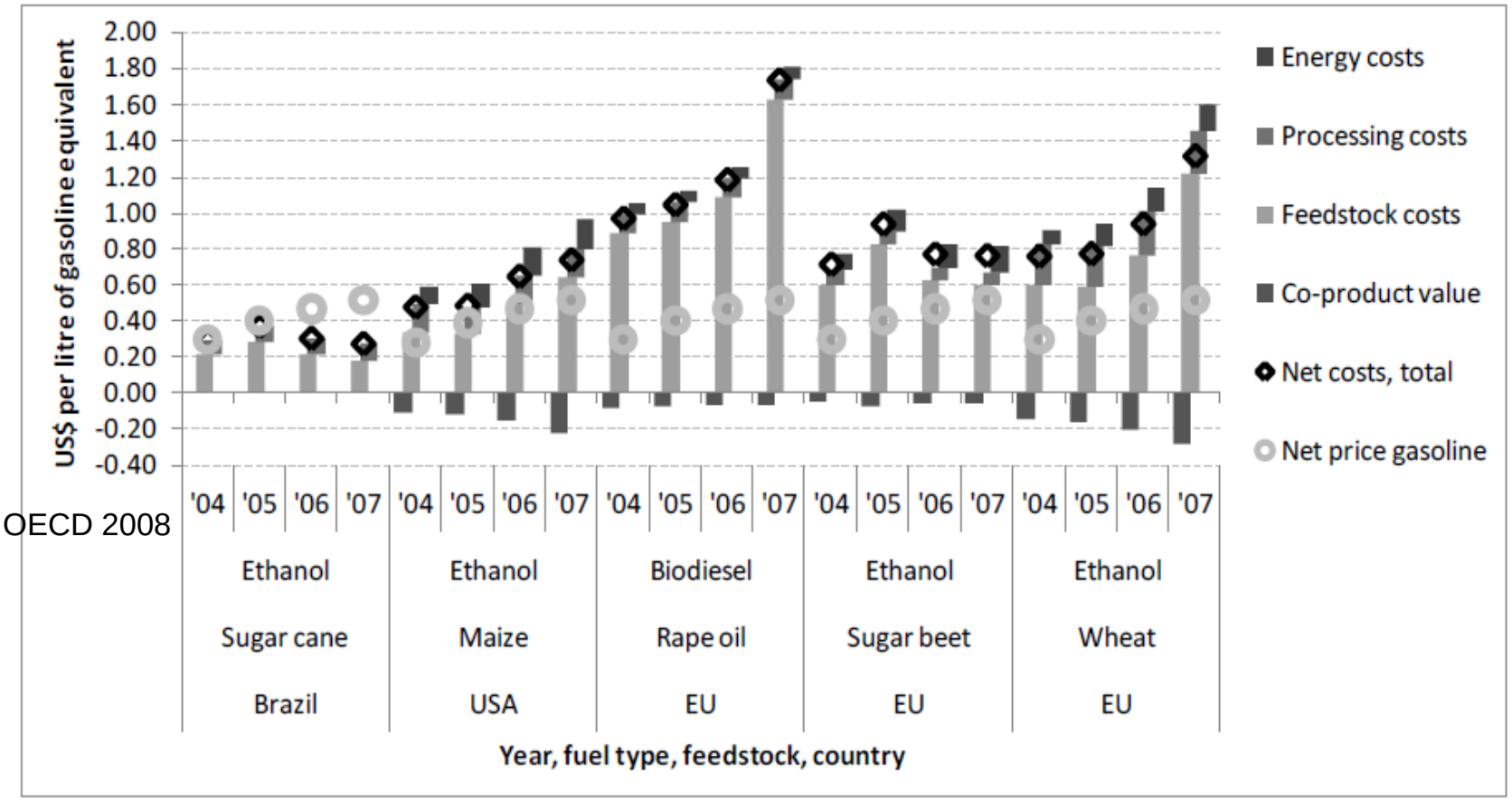
R&D Drivers 1. Rapid demand growth across sectors

- **Energy demand more than doubles in our lifetime**



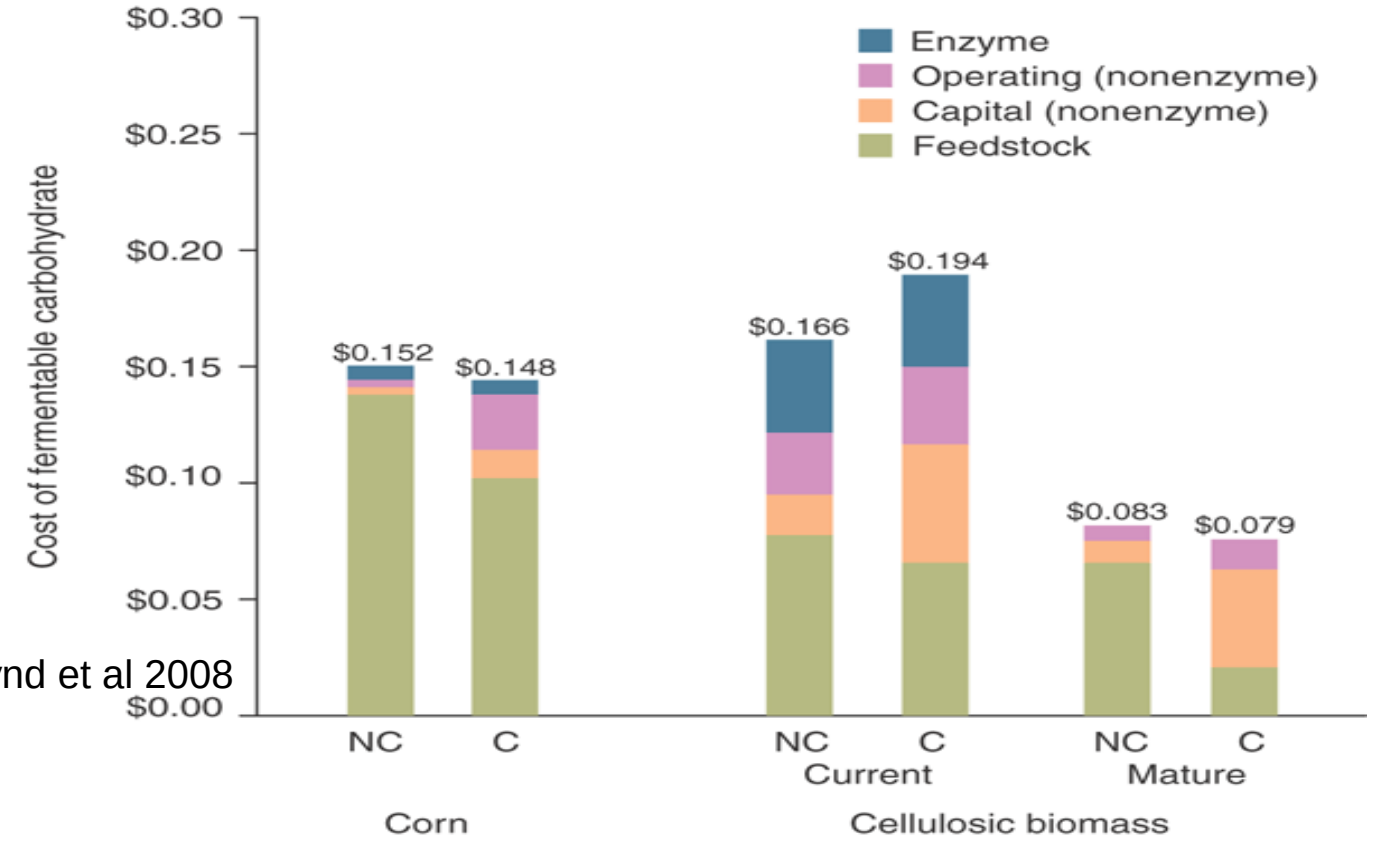
Source: IEA WEO 2004

R&D Driver 2. Costs of Feedstock, Processing, Energy



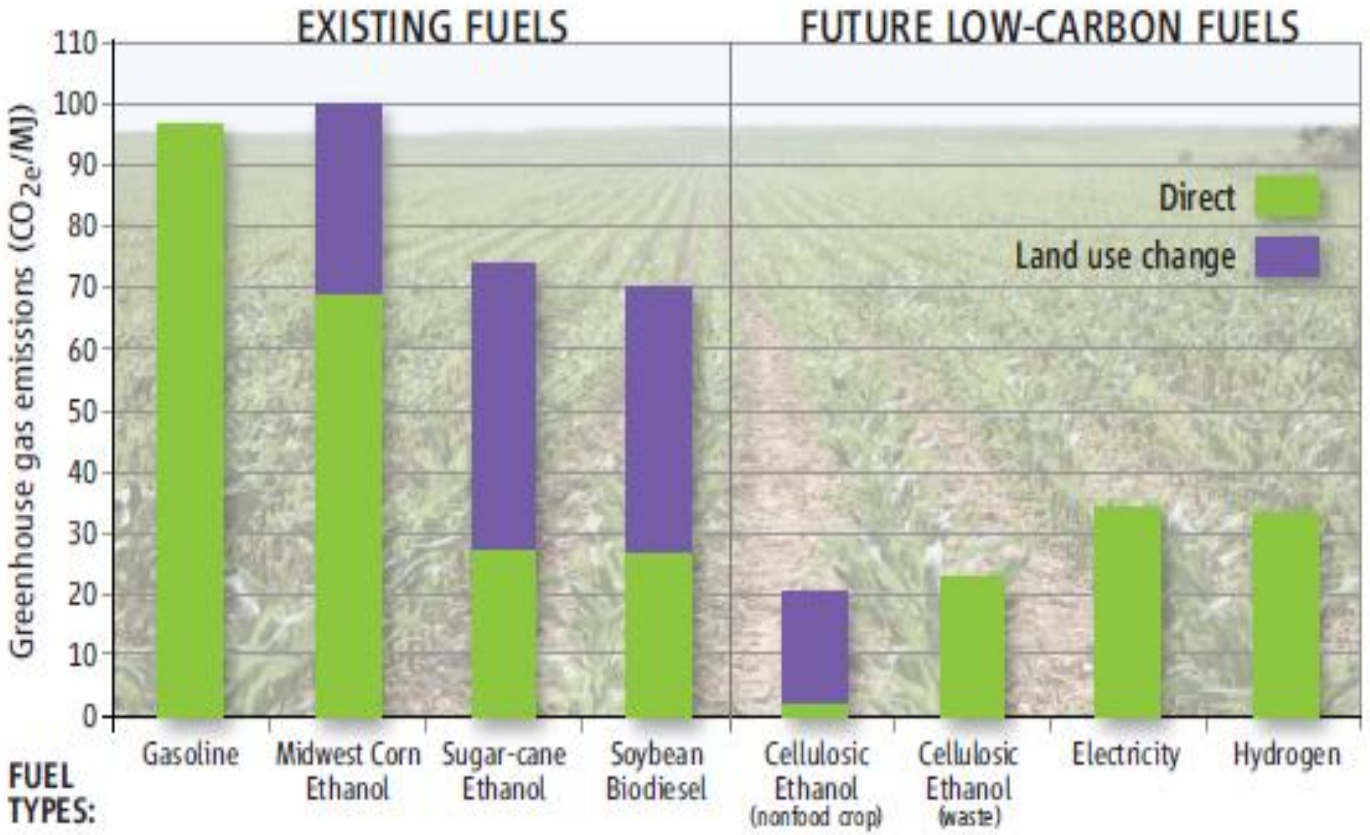
OECD 2008

R&D Driver 2 (cont.) Cost of Producing Corn vs. Biomass



Lynd et al 2008

R&D Driver 3. GHG Standards California (and elsewhere)



R&D Driver 4. Should not compete with food

Many developing countries do not allow food crops to be used for fuel

- India, China, South Africa biofuel policies forbid use of food crops

Others allow – Brazil, Argentina, US, Europe

- Bad publicity in US & Europe

Crops for BP to Consider – Not Jatropha

Poplar

Sorghum

Miscanthus

Switchgrass

Eucalyptus

Corn

Sugarcane

Miscanthus: An energy crop

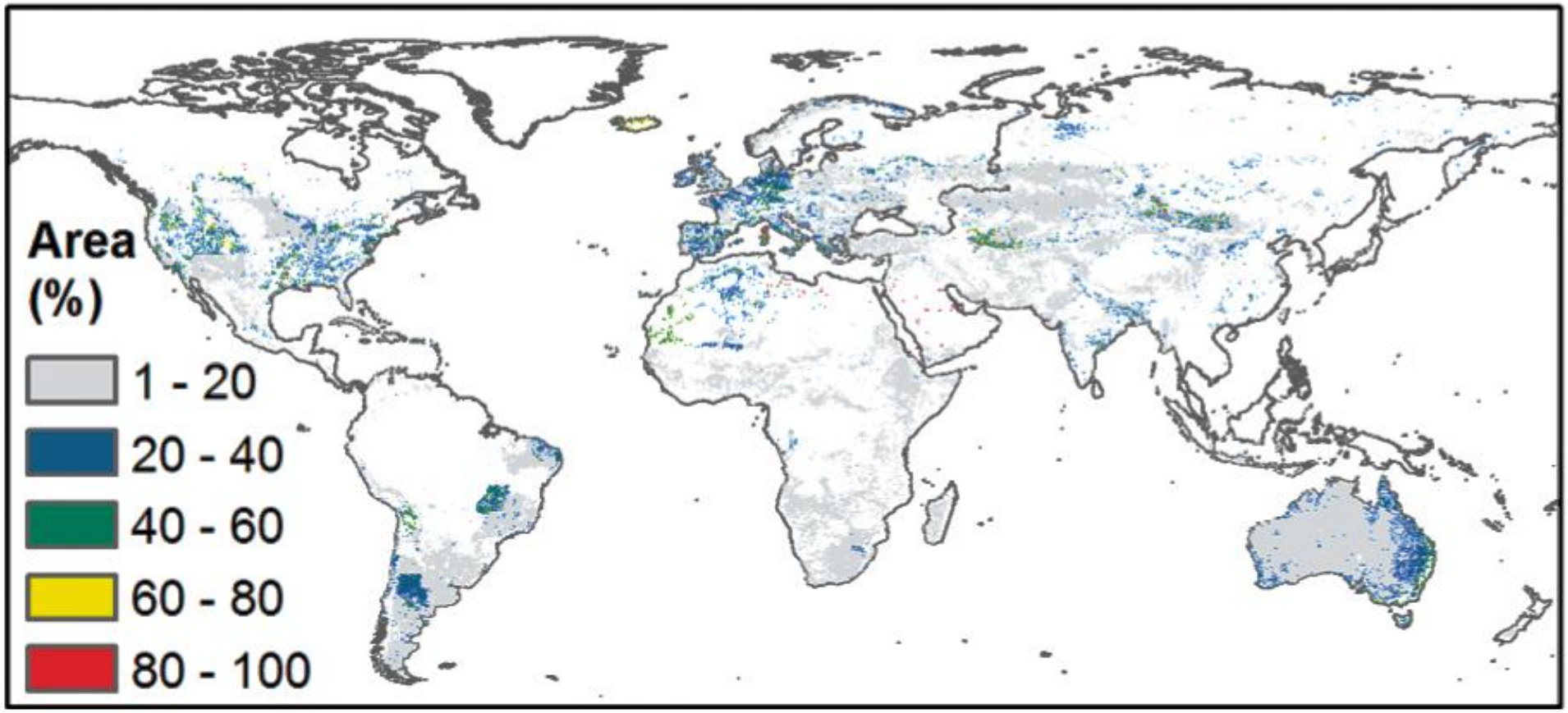
Yield of 26.5 tons/acre observed by Young & colleagues in Illinois, without irrigation

Courtesy of Steve Long et al

Distant future: Agave

Borland et al. (2009) J. Exp. Bot. doi:10.1093/jxb/erp118

Where? Ideally on the billion acres of agricultural land that has been abandoned (and stable non-OPEC countries)



Campbell et al., Env. Sci. Technol. (2008) 42,5791

EBI's production projections

- BP is committed to biofuels – they see in the end of oil, partially because they have less reserves than other oil majors
- Major investments in first generation biofuels
  - Recently announced $1 billion investment sugar based ethanol in Brazil and another equally large investment in Brazil is forthcoming – first plant on line 2010???
- Investments in second generation biofuels
  - 2012 $350 million plant in US completed
  - 2016 second plant will be finished
  - 2020 will be ready to replicate widely…..
  - Major expansion of second generation biofuels around 2024
- Algae is unlikely to be economical in foreseeable future

Generalizations from BP case?

- Oil companies research and investment
  - R&D structure – in house, collaborations with Universities and govt, many JVs
  - R&D focusing on
    - Cellulosic biofuels – sugarcane (energycane), grasses, poplar
    - Ethanol first, then butanol and “grassohol”
- Exception more interest in algae by Chevron for a long time & Exxon recently.

Which feedstocks are getting most R&D attention?

- First generation
  - Sugarcane – Monsanto invests $290 mil, BASF & Syngenta major increases
  - Corn – moderate increase in R&D
  - Sweet sorghum – major increase due to interest in sweet sorghum
  - Palm oil – moderate increase -
  - Rapeseed – not sure
- Second generation – cellulosic
  - Sugarcane - bagasse - energy cane
  - Miscanthus switchgrass
  - Algae
  - Wood – poplar, waste, forest clearing, plantations
  - Corn stover, wheat straw,
  - Jatropha
  - Camelina

Scenarios for increased production of cellulosic biofuels

- First use for bioenergy – will depend on cabon tax
- Second use – cellulosic biofuel 2024?

Technology transfer – Feedstock

- Corn/canola – moves everywhere except China through seed/biotech MNCs
- Sugarcane –
  - transfer was through national sugarmill coops and public sector
  - Recent investments in sugarcane genetics by Syngenta and Monsanto
- Energy canes
- Grasses – China to US and elsewhere – Mendel Biotech
- Sweet sorghum – Advanta (Indian based MNC)
- Jatropha – South-South through governments, small companies, BP when it looked promising
- Algae – Algenol and others to Mexico?

Environmental and Food Concerns

- Greenhouse gas impact
  - Direct
  - Indirect -
- Biodiversity impact
  - Rainforests
  - Orangutans
- Invasive species issues in US and Europe
  - Corn the only non-invasive species

Technology transfer – biofuel production

- Enzymes/yeast for ethanol/butanol –
  - Novozymes – research in Denmark, US, China, Brazil, India – sales global
  - BP brings Verenium to Brazil
  - Amyris – JV in Brazil
- Biofuel production facilities through capital investments
  - Sugarmills/producers – Brazil
  - Oilpalm plantations.- Malaysia
  - Multinational oil companies starting to invest in cellulosic…
  - National oil companies in Brazil, Malaysia, China

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Thanks

Lessons for climate change mitigation through biofuels and bioenergy

- Responding to:
  - Rising demand for fuel and energy –
  - Rising prices of oil
  - Concerns about global climate change, GHG, global warming…

- Private sector and governments respond with first generation biofuel – Off the shelf technology
  - Private plus government investments in US, Brazil, Europe
  - China public sector led growth
  - Public and private in India, South Africa, Argentina, Malaysia, Indonesia, Philippines

Lessons for biofuel

- Green revolution lessons –
  - Conventional technology from public sector and IARCs can have major impact food production but starting to run of steam
  - Must be adaptive research to different agricultural conditions
  - Technology can lead government institutional change
  - Africa starting to get technology….
- Biotech lesson - Technology can move very rapidly through private sector if politics and regulations allow movement
- Environmental multinationals who oppose biotech also oppose biofuels
  - Indirect GHG effects…
  - Invasive species – every feedstock except corn and sugarcane…
- Political opposition to oil multinational may be less of a problem with biofuels because large national oil companies a playing a large role in Brazil, China and elsewhere
- Who is investing in Genomics in LDCs? China and Sao Paulo, Brazil…
  - Brazil is applying in technology
  - China has not…. NRE