Upcoming Energy Club events

- Related bioenergy/ag Events:
  - Discussion Series: Agriculture and Energy
    - Tonight 6-7PM 26-210
  - Lecture Series: Biofuels, the future and the challenges
    - April 28th 6-7PM 4-231
- Special upcoming event
  - Tesla Motor's Powertrain Tech. and Manuf. Strategy
    - April 22nd 5-6:30PM 66-110
- Check www.mitenergyclub.org for more events!

Biofuels

MIT Energy Club

Energy 101 Series

April 14th, 2010

Outline of Presentation

- Introduction
- Feedstocks
- Technologies
- Markets/Economics
- Policies
- Conclusions

What can we do with biomass (in an energy context)?

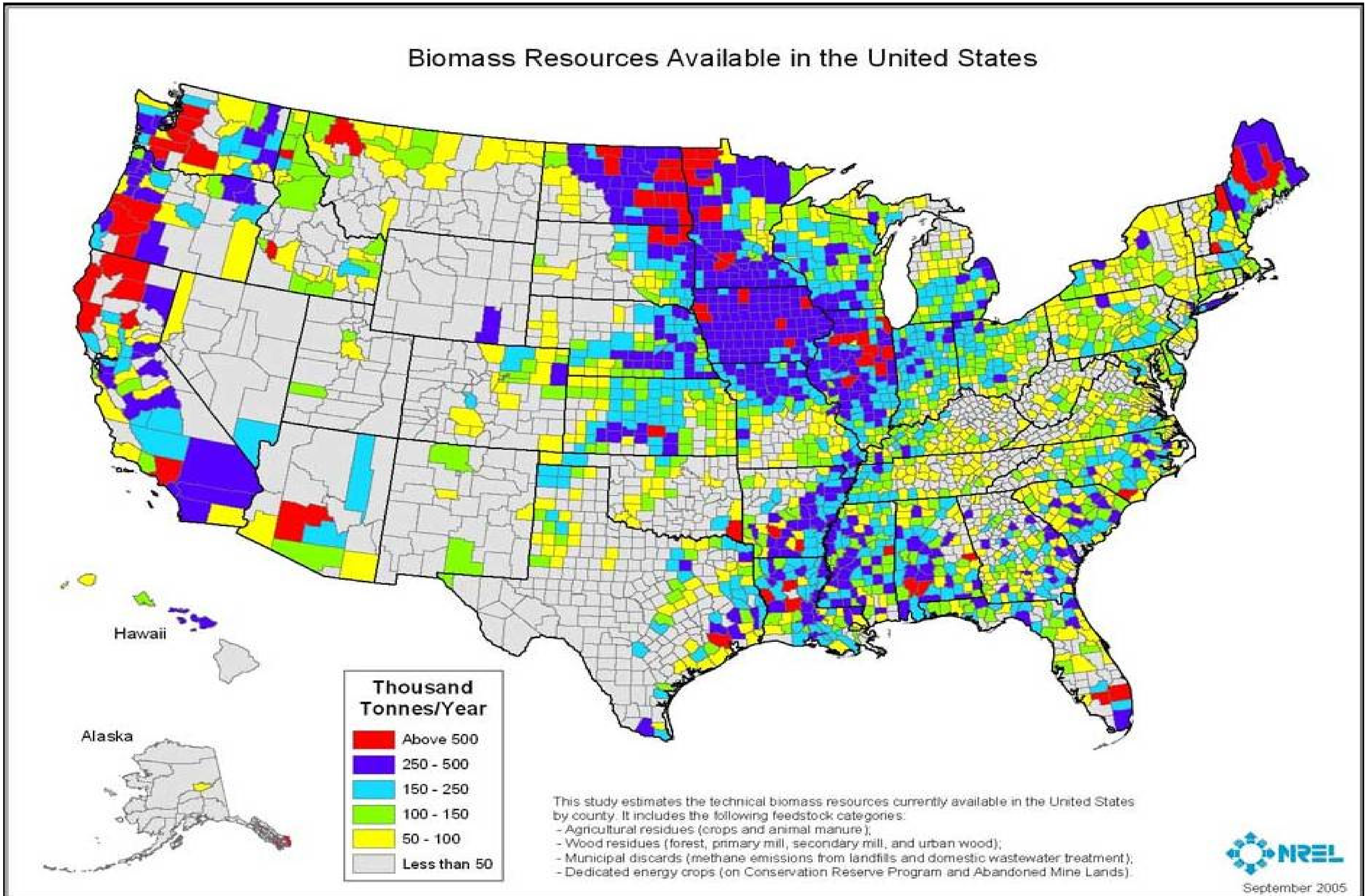
– Use it as food
– Use it as a food input
– Burn it to make heat
– Burn it to make electricity
– Convert it to other “high quality” fuels
– Other?

What is biomass?

- Solid carbon-based fuel (like coal)
  - H:C ~1.5 , O:C ~1
  - Significant metals, Sulfur, Nitrogen
  - Minor elements come from soil
    - Nitrogen fertilizers often required
- Wet: about 50% water before drying
  - Low energy density ~9 MJ/kg wet
- Diffuse, relatively low energy density: expensive to harvest, ship.
- Annual cycle: biomass available only at harvest time, may need to be stored.

Biomass: The Source

- Photosynthesis stores ~300 EJ/yr as biomass energy
  - Human energy use ~400 EJ/yr
  - Carbon cycle: plants die, decay to CO2
  - In fertile areas ~ 10^{-5} EJ/(km)^2/yr
    - Requires ~250 kg H_2O to grow 1 kg biomass
  - Earth's total land surface ~10^8(km)^2
- For large scale biomass energy NEED LOTS OF LAND (even much more than solar) and WATER
- If you have spare land and fresh water, relatively inexpensive to grow and harvest (e.g. much less capital than solar!)


Biomass Resources Available in the United States
Hawaii
Alaska
Thousand Tonnes/Year
Above 500
250 - 500
150 - 250
100 - 150
50 - 100
Less than 50
This study estimates the technical biomass resources currently available in the United States by county. It includes the following feedstock categories:
- Agricultural residues (crops and animal manure);
- Wood residues (forest, primary mill, secondary mill, and urban wood);
- Municipal discards (methane emissions from landfills and domestic wastewater treatment);
- Dedicated energy crops (on Conservation Reserve Program and Abandoned Mine Lands).
NREL
September 2005

Classification of Biomass Resources

Plant Derived

- Herbaceous Biomass
  - Grasses (Switchgrass)
- Woody Biomass
  - Wood (Poplar)
- Sugary Biomass
  - Sugars from plants (Sugarcane)
- Starchy Biomass
  - Cereal grains (Corn)
- Oils
  - Oil seeds (soy), algae

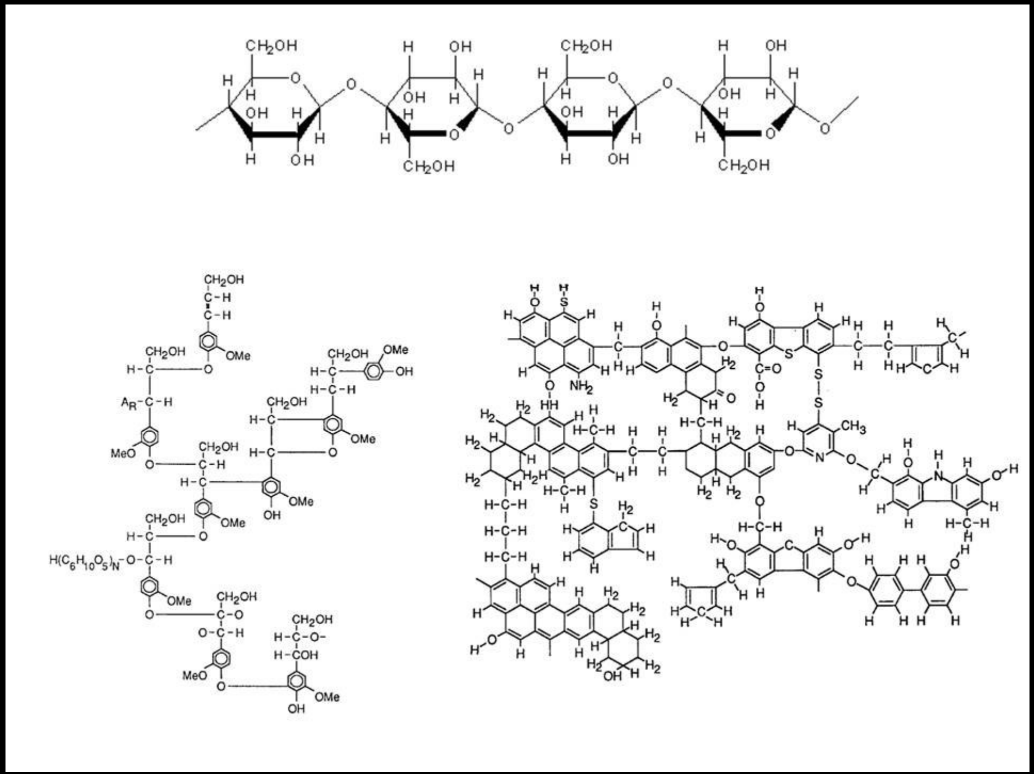
Other

- Municipal Waste
- Industrial Waste
- Animal Wastes

State.ia.us

Chemical and Physical Properties of Ligno-Cellusic Biomass (and Coal)

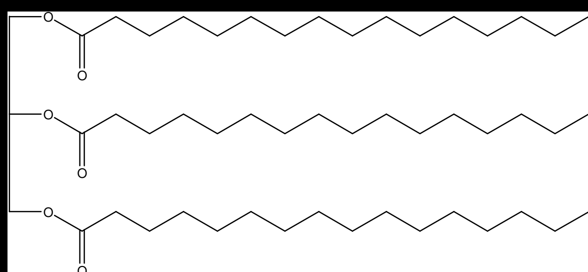
- Lignin
  - Structural material
  - High C:H, C:O ratios
  - High Heating Values
- (Hemi)-Cellulose
  - Polymers of sugars
  - Lower C:H , C:O ratios
  - Ideal for fermentation
- Coal
  - High heating values
  - dense



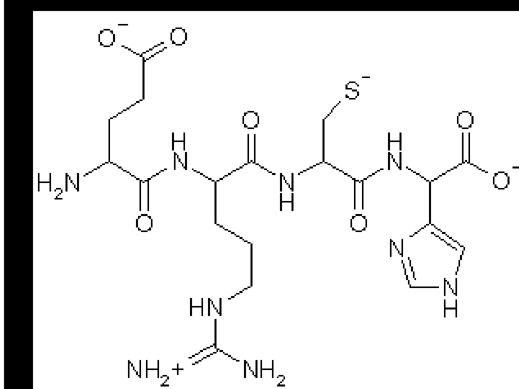
Adapted from: Tillman, 2000

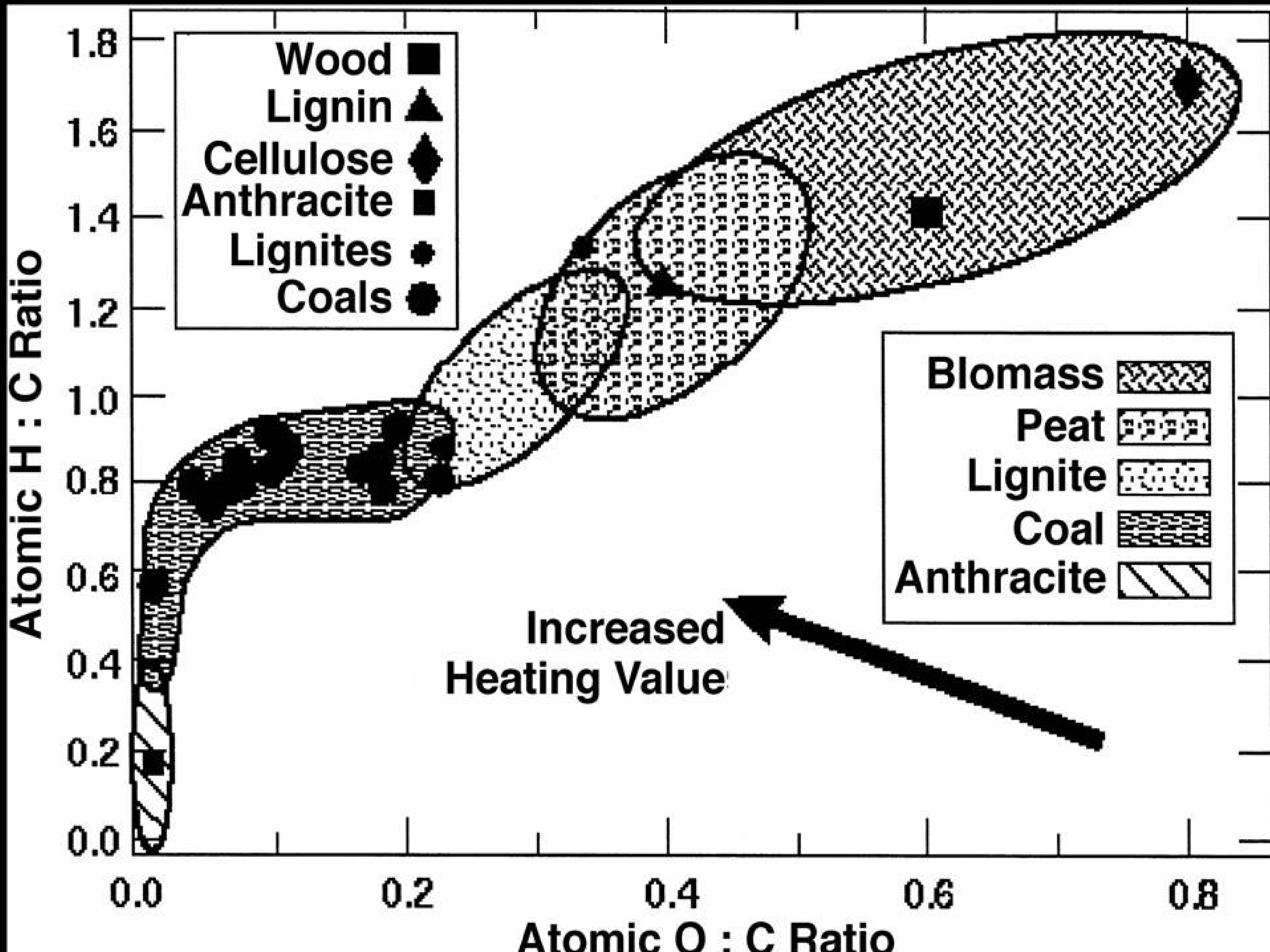
The other components in biomass

Fats



Proteins





Heating Values of types of biomass and coal (Jenkins, 1998)

Technologies

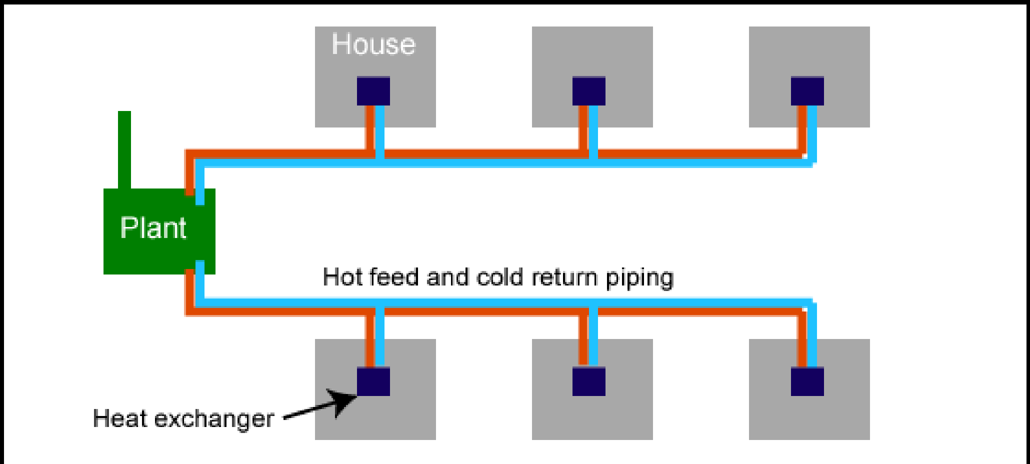
- For…
  - Heat
  - Electricity
  - Combined Heat and Power (CHP)
  - Fuel upgrading (i.e. liquid/gaseous fuel production)

Technology for heat production

- Traditional use of biomass
- Domestic heat
  - Fireplaces are inefficient (even negative efficiency)
  - Home boiler or forced air systems generally below 25kWth (33.5 HP)
  - Common in Scandinavian countries and in North America

Technology for heat production (cont.)

- Larger scale “district heating” is a possibility
- $100kW_{th}$ – $10MW_{th}$



Technology for electricity production

- Biomass can be used as a substitute for coal in traditional Pulverized Fuel (PF) systems
  - This is a technology that is already employed at large scale
  - Biomass offers a few challenges for adaptation due to physical structure and chemistry. This can be overcome.
  - Scale is issue (500MW-1.5GW!)

Technology for Electricity Production

- Integrated Gasification and Combined Cycle (IGCC)
  - New technology being considered for use with coal for ease of coupling Carbon Capture and Sequestration (CCS)
  - Biomass could be used as a feedstock as well. Scale an issue.
  - With CCS could achieve negative CO_2 intensity…

Technology for CHP

- Combined Heat and Power (CHP) is the coupling of a district heating system to a power plant
- Increases the utilization efficiency of the fuel dramatically and allows for improved economics
- Allows for load shifting from power production to heat and vice-versa
- “Waste heat” from power production now utilized

Fuel Upgrading

- A solid fuel is fine for stationary applications, not so great for mobile applications.
  - Cannot be used in a compact engine such as an Internal Combustion Engine (ICE)
  - Here, liquid and gaseous fuels take the cake.
- Liquid and gaseous fuels can be more easily transported

Fuel Upgrading (cont)

- Main technology classifications
  - Biological/Enzymatic fuel production
    - Today's biofuel industry is based on this route
  - Oil upgrading
    - biodiesel
  - Thermochemical fuel production
    - Tomorrow's biofuel industry will be based on this route*

*Disclaimer: I work on thermochemical production routes

Fuel Upgrading (cont.)

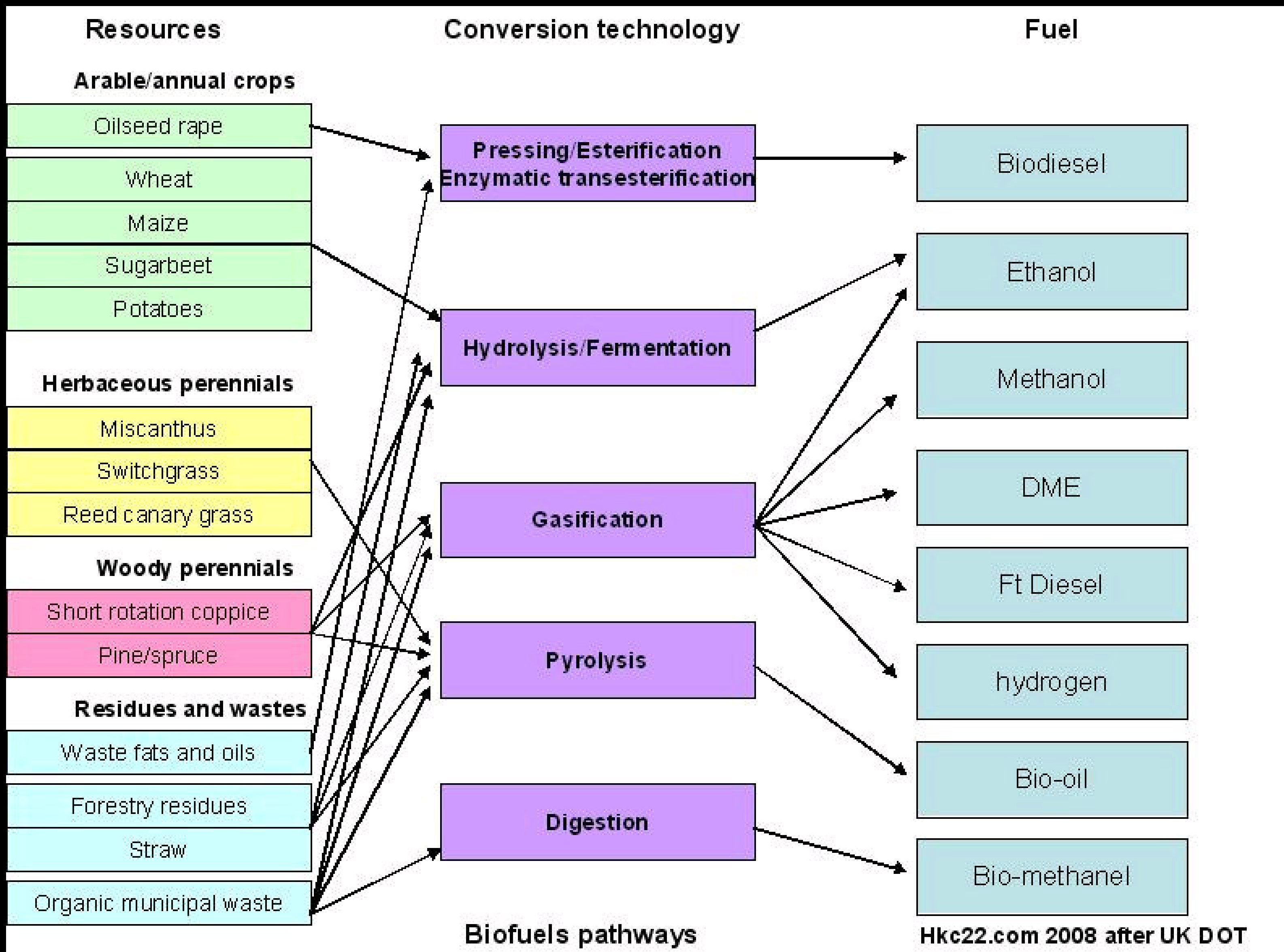
- Biological/Enzymatic biofuel production:
  - Use specialized microbes to convert certain biomolecules to fuels
  - Must be metabolic products.
  - Can make – Ethanol, Butanol, Hydrogen, Biogas (methane and other assorted gases)
  - Challenges lie in metabolic engineering, and processes which avoid reactor contamination

Fuel Upgrading (cont.)

- Oil upgrading:
  - Biodiesel is produced by reacting vegetable or animal oils/fats with short chain alcohols (methanol or ethanol)
  - This is a simple and proven production scheme.
  - The challenges lie in feedstock production and costs

Fuel Upgrading (cont.)

- Thermochemical biofuel production:
  - Biomass is first ‘gasified’ to creat ‘syn-gas’, a mix of hydrogen and carbon monoxide
  - Catalytic chemistry is then performed on the syn-gas to produce a wide range of fuels or chemicals: alcohols, synthetic hydrocarbons, ethers, monomers, etc.
  - Much of the technology comes from the petrochemical industry (been proven on the large scale)
  - Challenges are upstream (biomass gasification)

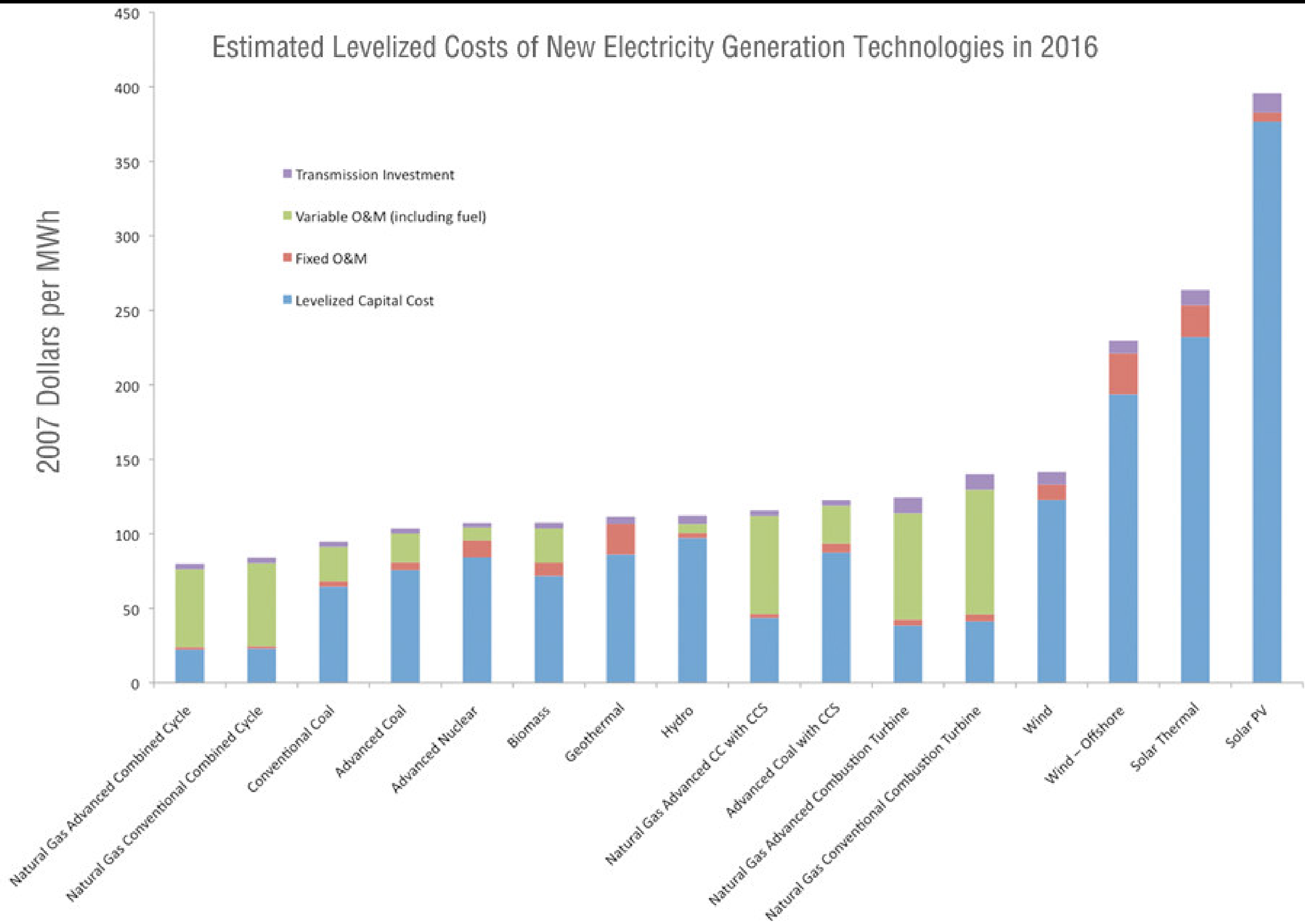

Resources
Conversion technology
Fuel
Arable/annual crops
Oilseed rape
Wheat
Maize
Sugarbeet
Potatoes
Herbaceous perennials
Miscanthus
Switchgrass
Reed canary grass
Woody perennials
Short rotation coppice
Pine/spruce
Residues and wastes
Waste fats and oils
Forestry residues
Straw
Organic municipal waste
Pressing/Esterification
Enzymatic transesterification
Hydrolysis/Fermentation
Gasification
Pyrolysis
Digestion
Biodiesel
Ethanol
Methanol
DME
Ft Diesel
hydrogen
Bio-oil
Bio-methanel
Biofuels pathways
Hkc22.com 2008 after UK DOT

Economic Considerations

- Heat
  - Depends on a number of factors
  - Can be economical for undeveloped areas away from integrated natural gas system.
    - Rural areas with available resource
    - Developing countries
  - Economy comes with scale
    - Can be economical for large installations (Universities, neighborhoods)

Economic Considerations (cont.)

- Electricity
  - Would compete with coal
  - Coal is cheep and denser/easier to transport than biomass
  - Economics improve drastically in a carbon constrained economy (carbon tax or cap-and-trade)



Average National Levelized Costs of Generating Technologies in the Updated 2009 Annual Energy Outlook (AEO)
Energy Information Administration, April 2009, SR-OIAF/2009-03, http://www.eia.doe.gov/oiaf/servicerpt/stimulus/index.html
Explanation of data at http://www.instituteforenergyresearch.org/2009/05/12/levelized-cost-of-new-generating-technologies

IER INSTITUTE FOR ENERGY RESEARCH

Economic Considerations (cont.)

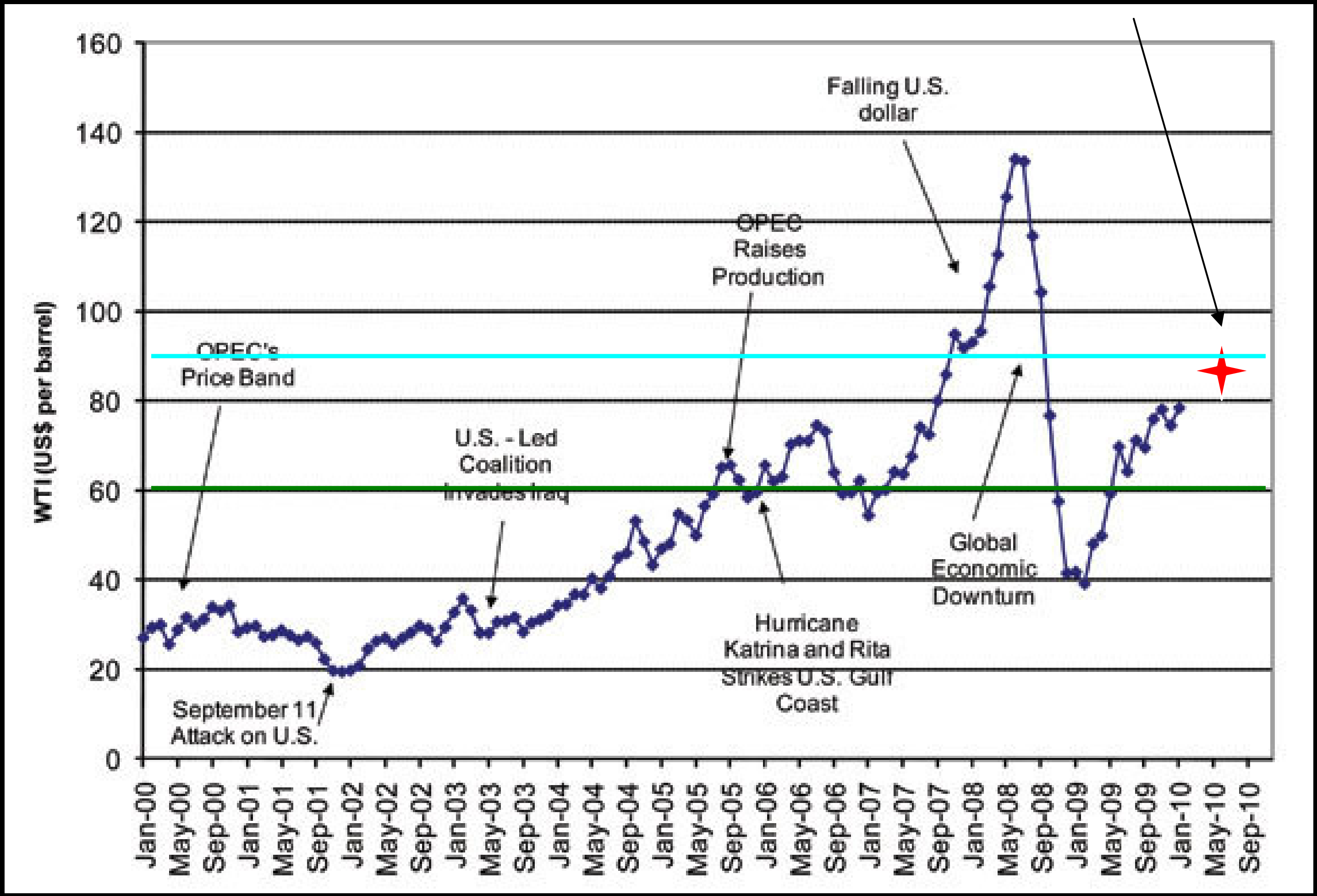
- Fuels
  - Must compete with petroleum derived fuel
  - A decent rule of thumb is biofuels (read ethanol) are profitable when oil is above ~$60/bbl (with subsidy!)
    - The current biofuel subsidy is about $0.50/gal… ~$30/boe!
    - Biodiesel is even more expensive…
  - In a carbon constrained economy the economics are much more favorable

Biodiesel is a pretty good fuel. Where does it come from?

- Feedstock: oil crops, used cooking oil, etc.

- Problem is SCALE, use of farmland or rainforest:
  - Oil Palm: 600 gallons/acre/yr
    - Replacing Asian rainforest with oil palm plantation to meet EU biodiesel demand.
  - Rapeseed (Canola): 127 gallons/acre/yr
  - Soybeans: 48 gallons/acre/yr
    - If you sell it for $2/gallon, that is only $96/year for use of an acre of farm land.
    - Farm land goes for anywhere form $2000 - $3000 per acre
      - on a 30 year note with 5% interest an annual payment of ~$160
      - Biodiesel from soy cannot cover the payment!

Today’s opening spot price $84.05/bbl



- Regulatory compatibility
- Food versus fuel
- Land-use changes
- The complete policy landscape

ILLUMINATING THE TRADE-OFFS

Regulatory Compatibility

- Policy influences fuel choice through the Clean Air Act
  - Limits are set on the amount of criteria pollutants that can be emitted by certain vehicles.
  - Controls make-up of fuels.
  - Will affect transportation fuels and large electricity installations

Food Versus Fuel

- Increasing demand for biofuels may incentivize farmers to switch land away from food production
  - Decreasing food supplies
  - Increasing food prices
- Some argue that this was the case in 2008.
  - Data for making a conclusion either way is somewhat lacking.
  - Innovation in agriculture is far outpacing demand growth.

Guardian.co.uk 2008

Land-use Changes

- Increasing demand for biofuels may incentivize farmers to put more land into production
  - The rainforests for soy/sugar cane
  - Jatroptha in Indonesia
- How do we quantify these secondary effects?
  - Measuring a counterfactual

Guardian.co.uk 2008

The Biofuel Policy Landscape

- Blender-Tax Credits (Volumetric Ethanol Excise Tax Credit, VEETC)
  - 45 cents per gallon tax credit for ethanol blenders.
  - This year ~9 billion gallons of ethanol were used
  - This subsidy creates a perverse incentive to produce low energy density fuels (ethanol instead of Fischer-Tröpsch Diesel)

Biofuel Policy Landscape (cont.)

- The Energy Independence and Security Act (EISA) requirements
  - In 2022 36 billion gallons of biofuel use is mandated
    - Of this, majority must be advanced/cellulosic
  - We will not meet our target in the next couple years
- EPA limits the percentage of ethanol which can be blended in RFG
  - Oxygenate requirements
  - Blending wall

General Conclusions

- Biomass is a renewable source of fixed carbon
- Early adoption will continue to be in the realm of transportation fuels and heat applications
- Biomass sourcing must be scrutinized for best sustainable practices
- Will be a major part of any serious push for clean energy