LIGNO-CELLULOSIC BIOMASS TO ETHANOL- WHERE DO TECHNOLOGIES STAND TODAY?

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Public Interest Energy Research (PIER) Program

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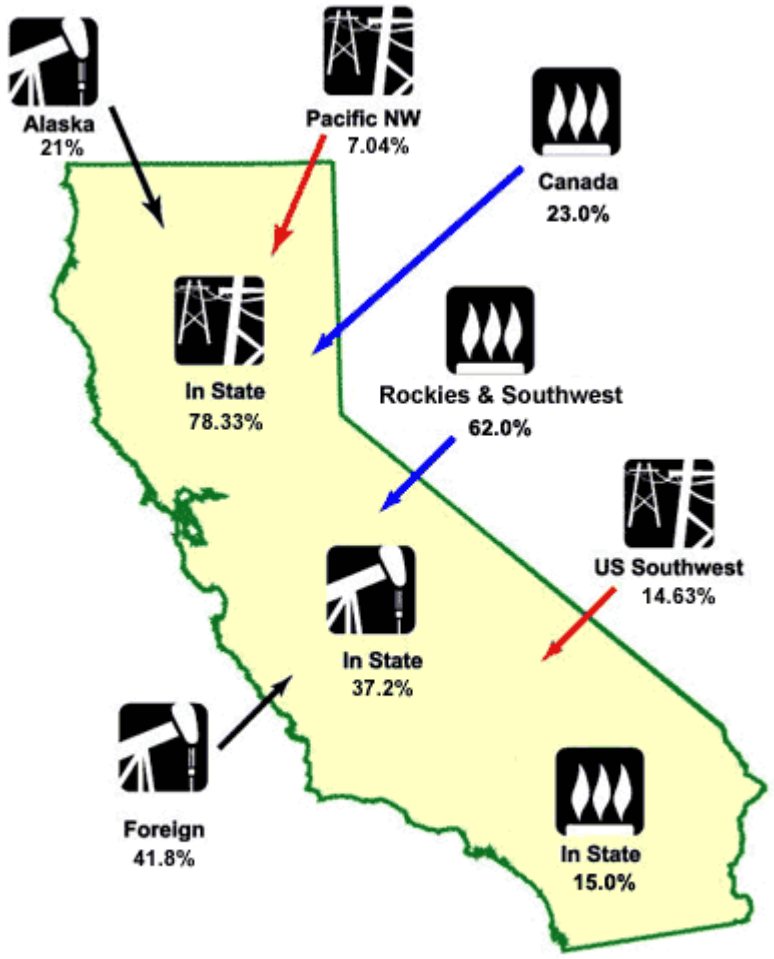
Outline

- PIER Program Overview
- Global Ethanol Development (Corn/Sugar)
- Sugar/Starch vs LignoCellulose Feedstocks
- LignoCellulose Ethanol
  - Conversion Pathways
  - Technology Development
  - Outlook in California
  - Existing Challenges
- Conclusions

PIER Program Overview

- California's Energy Picture
- Key Policy Drivers for Alternative Energy/Renewables
- Public Interest Energy Research Program (PIER)
- Renewable Energy
  - Biomass
  - Solar
  - Wind
  - Geothermal (Geothermal Program)
- Environmentally Preferred Advance Generation

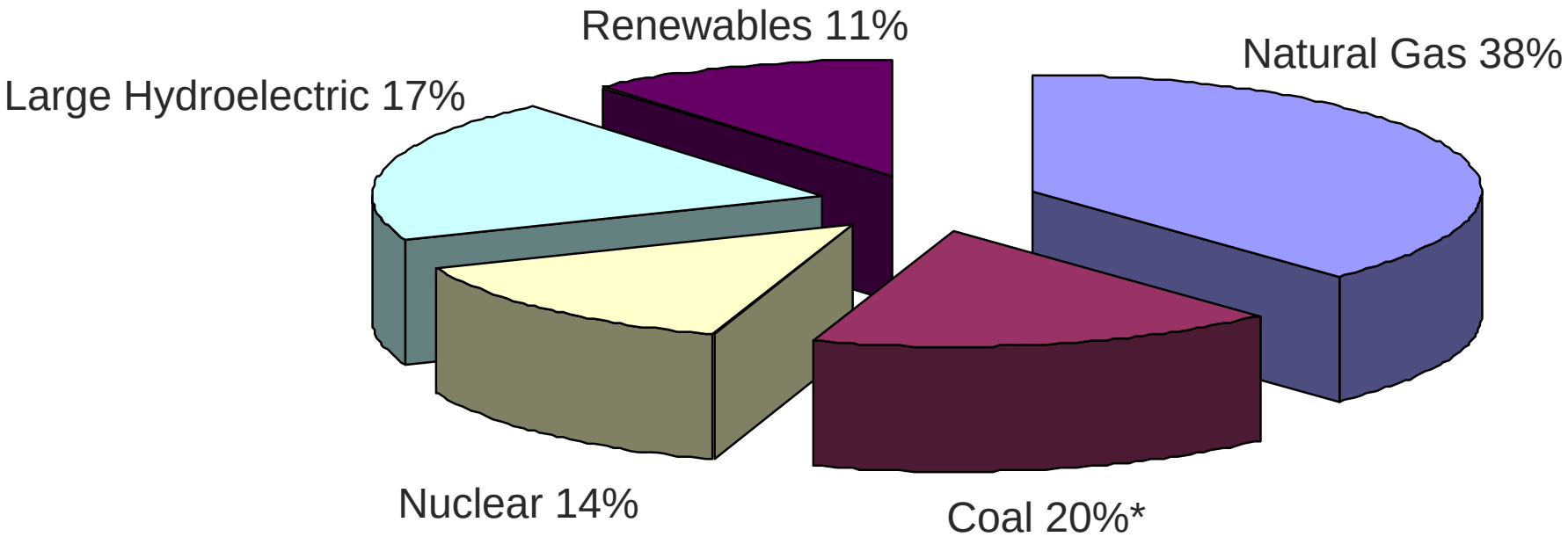
California's Energy Picture



CALIFORNIA'S ENERGY SOURCES

- **Population:** 35,655,404 (2004) ranked 1st
- **Total Energy Consumption:** 7.9 quadrillion Btu (2001), ranked 2nd
- **Total Petroleum Consumption:** 78.4 million gallons per day (2002), ranked 2nd
- **Gasoline Consumption:** 42.5 million gallons per day (2002), ranked 1st
- **Distillate Fuel Consumption:** 10.3 million gallons per day (2002), ranked 2nd
- **Liquefied Petroleum Gas Consumption:** 1.7 million gallons per day (2002), ranked 6th
- **Jet Fuel Consumption:** 11.8 million gallons per day (2002), ranked 2nd
- **Natural Gas**: Total natural gas consumption including residual, commercial, industrial, and power industry in California is 2,366,399 MMcf (2004).
- **Electricity:** Total summer capacity is 58,306 MW (2004)

California Electricity Production 2005



*Intermountain and Mohave coal plants are considered in-state, since they are in California control areas.

Key Drivers of California Alternative Energy Policies

- Renewables Portfolio Standard, 20% by 2010 and 33% by 2020
- Integrated Energy Policy Reports (IEPR) (2003, 2004 update, 2005)
- Energy Action Plan (EAP) I and II (published 2003 and 2005 respectively)
- Governor's 2003 / 2004 IEPR response and Ten Point Plan
- California Solar Initiative (CPUC Proceeding R.06-03-004)
- Governor's Executive Order S-06-06 –biomass & biofuels
- Bioenergy Action Plan (July 13, 2006, Governor announces action plan to reduce petroleum dependence and improve air quality)
- Governor's GHG Reduction Targets (Executive Order S-3-05)
- US 2005 Energy Policy Act
- Western Governor's Association (Charter, 2005 Annual Report, 2003 Policy Roadmap)
- AB 32 (Nunez) - California Global Warming Solutions Act of 2006

CEC Public Interest Energy Research Program

- IOU Ratepayer-funded program launched in 1997
- Addresses electricity, natural gas, and transportation
- $80M annual budget; nearly $400M in projects
- A leader in no/low-carbon technology and global climate change research programs
  - Efficiency and Demand Response
  - Renewables
  - Clean Fossil Fuel Generation – Distributed Generation, Combined Heat & Power
  - Transportation
  - Energy Systems Research – Transmission and Distribution, Grid Interconnection
  - Environmental Impacts – Air, Water, Climate, Communities
- Strong emphasis on collaborations
  - Avoid duplication/builds on past work/ensures relevance
  - Regular coordination with IOUs via the Emerging Technology Coordinating Council to transition research to the marketplace
  - State Agency Partnerships (DGS/DOF, ARB, T-24)
  - Market Partnerships (California builders, Collaborative for High Performance Schools, California Commissioning Collaborative, major equipment manufacturers)
  - Use California Capabilities (Universities, National Laboratories, High Technology Companies)
  - Leverage/complement Federal Investments

SB 1250 Goals for PIER Are Solution- Focused

General Goal

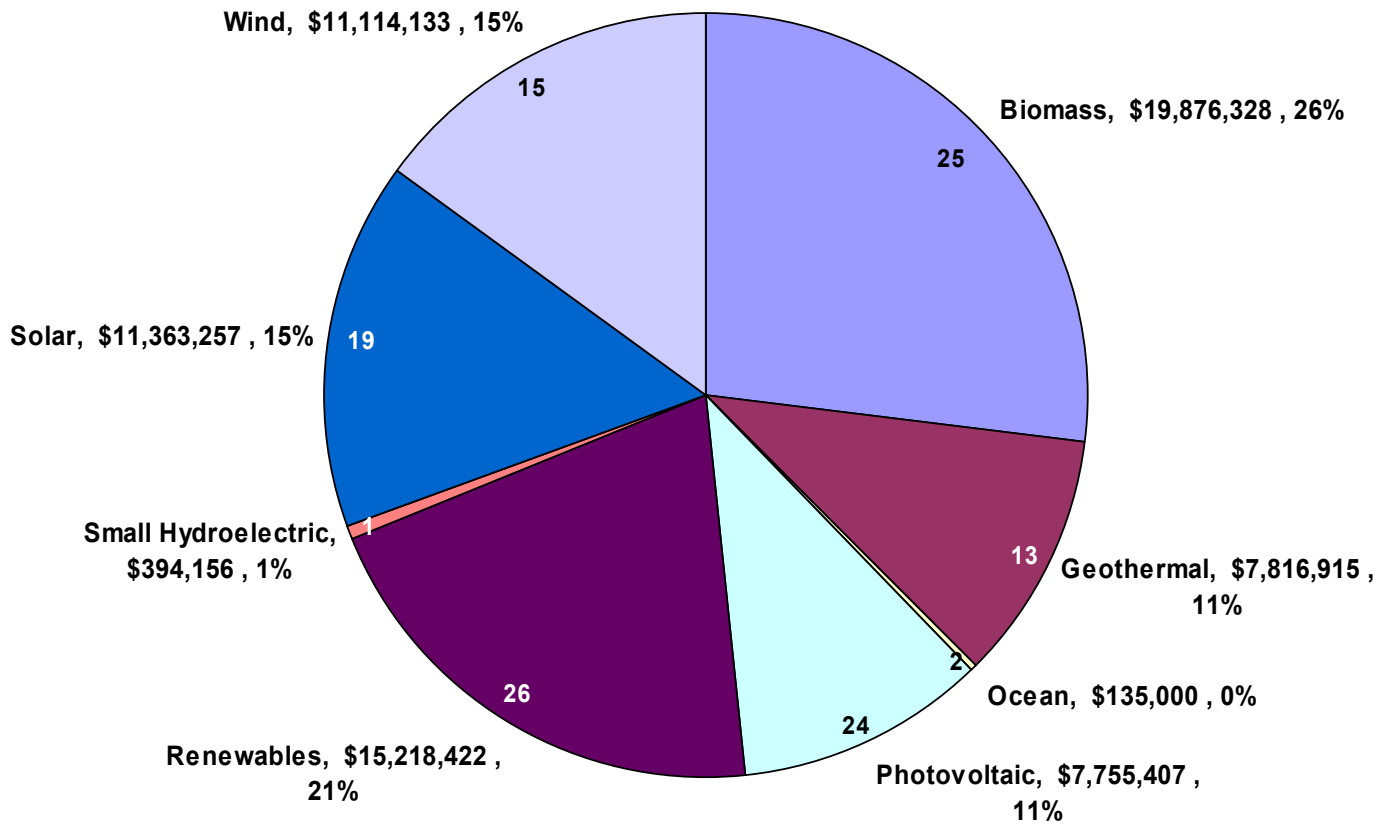
- "Develop and help bring to market, energy technologies that provide increased environmental benefits, greater system reliability, and lower system costs"

Specific Goals

- Develop and help bring to market
  - "Advanced transportation technologies that reduce air pollution and greenhouse gas emissions beyond applicable standards, and that benefit electricity and natural gas ratepayers.
  - "Increased energy efficiency in buildings, appliances, lighting, and other applications beyond applicable standards, and that benefit electric utility customers.
  - "Advanced electricity generation technologies that exceed applicable standards to increase reductions in greenhouse gas emissions from electricity generation, and that benefit electric utility customers.
  - "Advanced electricity technologies that reduce or eliminate consumption of water or other finite resources, increase use of renewable energy resources, or improve transmission or distribution of electricity generated from renewable energy resources."

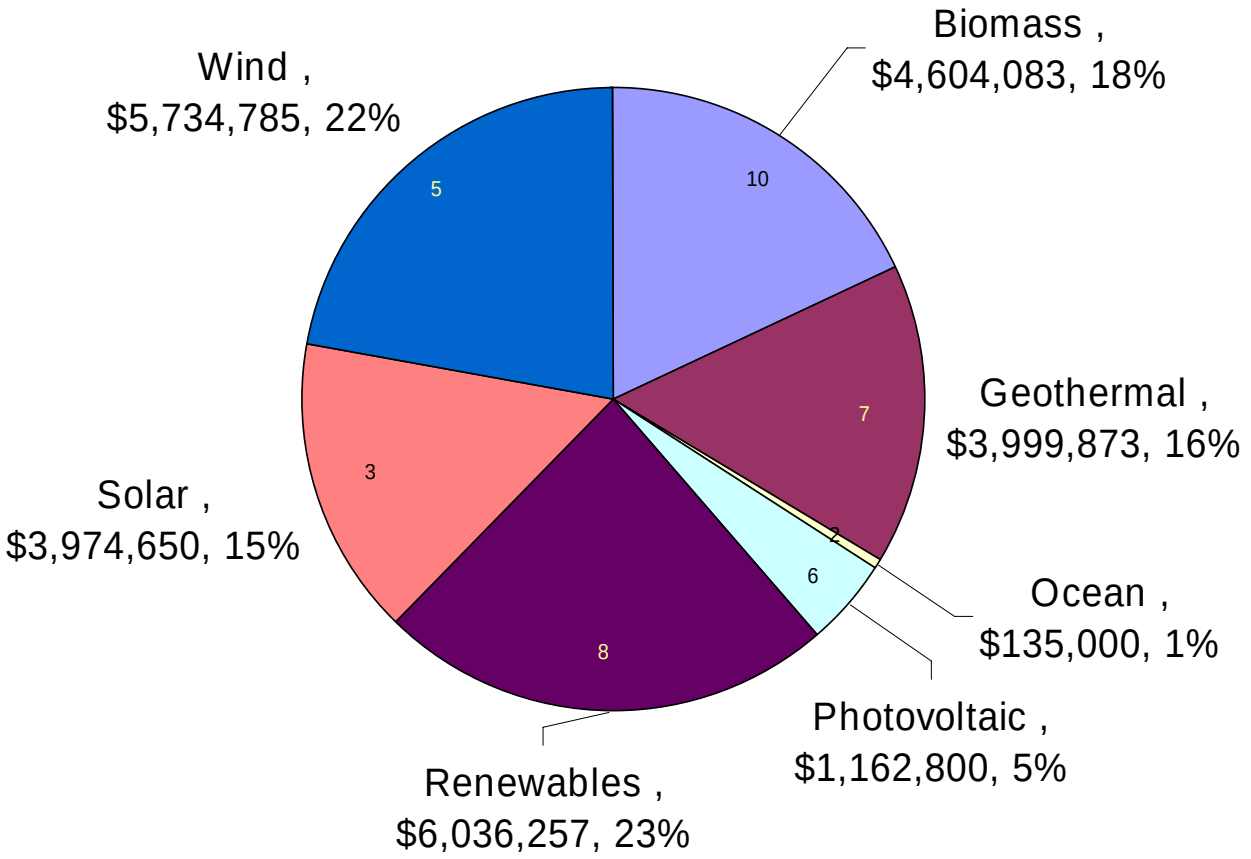
PIER Portfolio Summary

Renewables Projects - Active and Closed
125 Projects, $73.7 Million

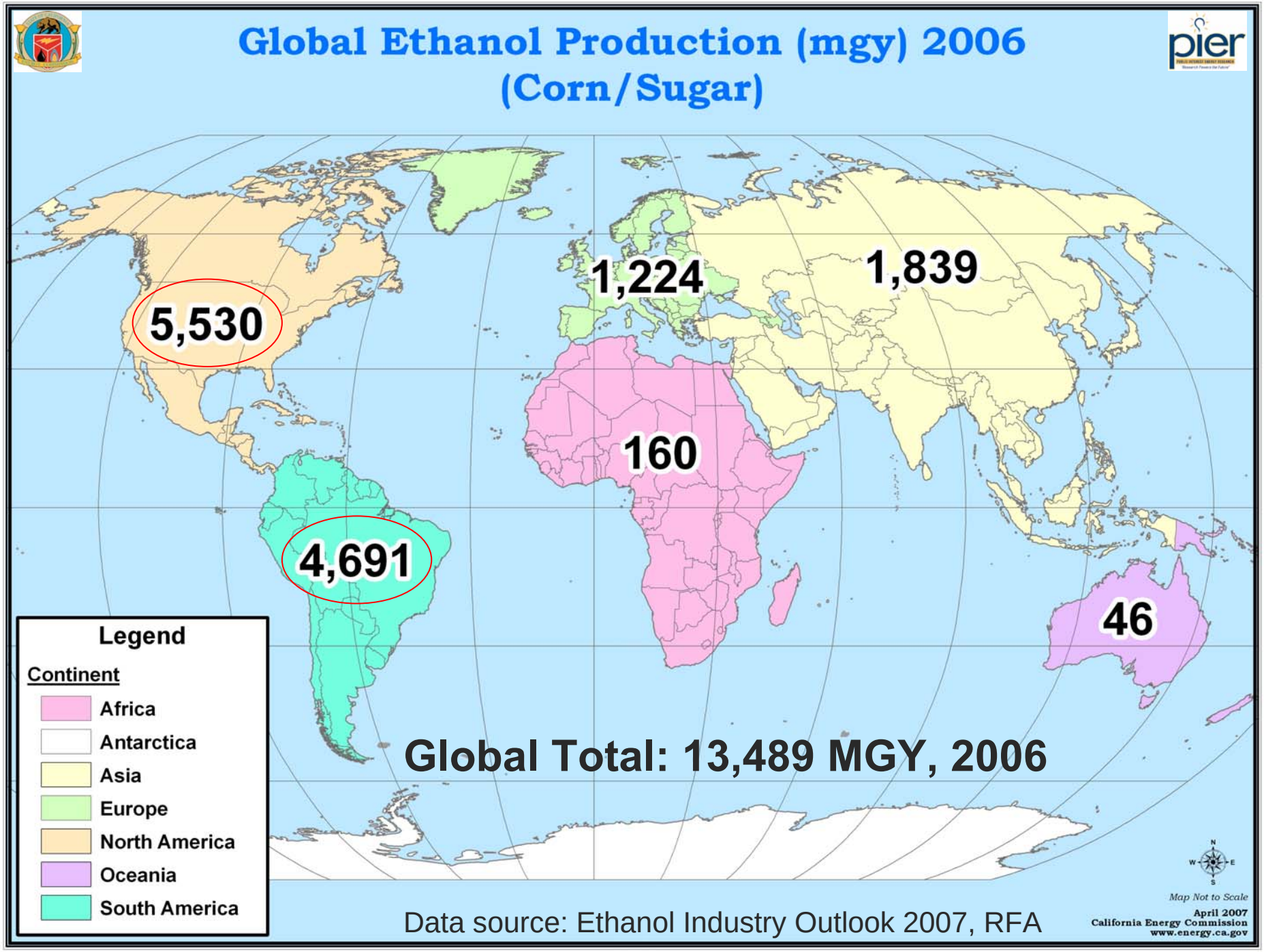


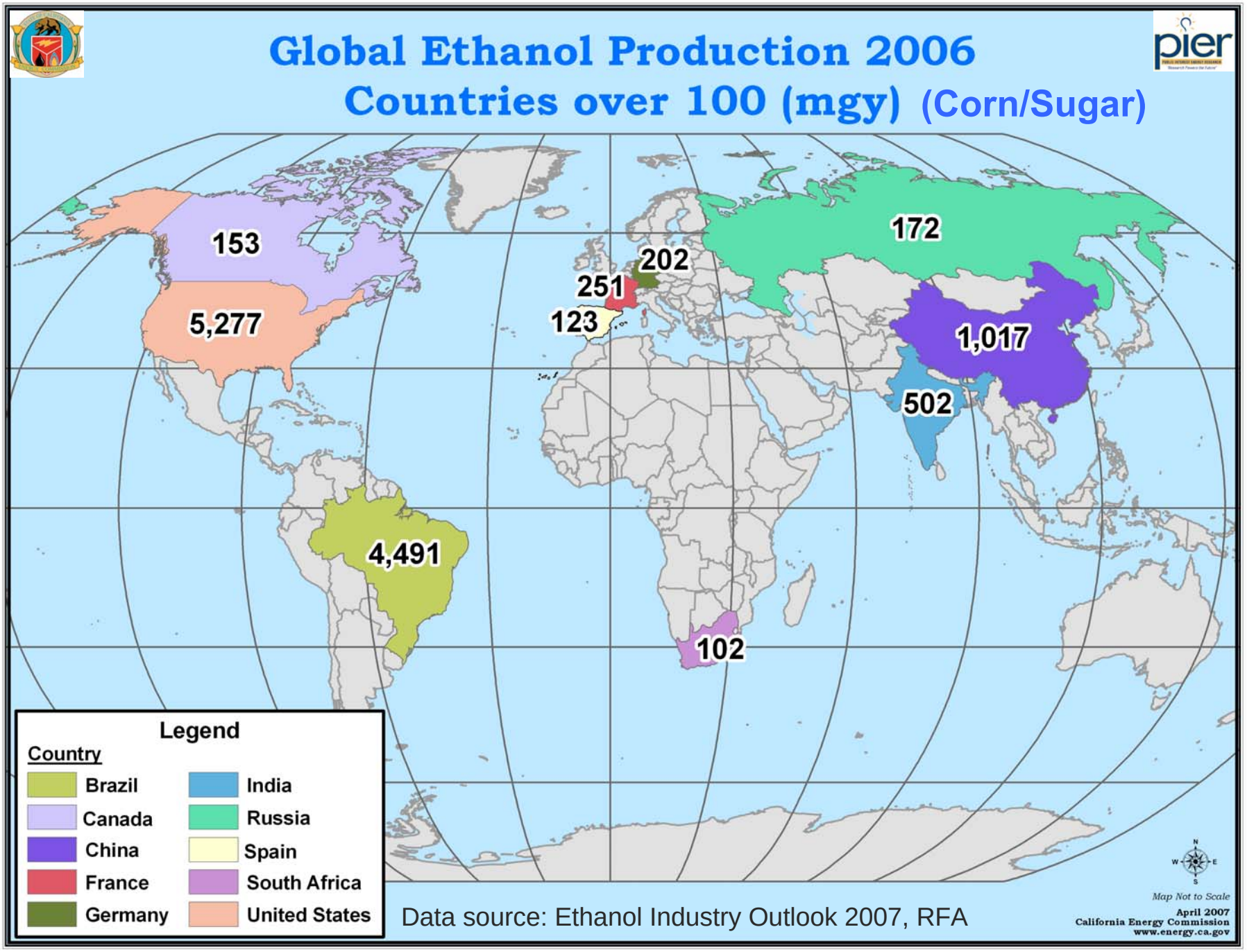
PIER Portfolio Summary

Renewables Projects - Active
41 Projects, $25.6 Million



Global Ethanol Development (Corn/Sugar)


Global Ethanol Production (mgy) 2006
(Corn/Sugar)
pier
5,530
1,224
1,839
160
4,691
46
Legend
Continent
Africa
Antarctica
Asia
Europe
North America
Oceania
South America
Global Total: 13,489 MGY, 2006
Data source: Ethanol Industry Outlook 2007, RFA
Map Not to Scale
April 2007
California Energy Commission
www.energy.ca.gov


Global Ethanol Production 2006
Countries over 100 (mgy) (Corn/Sugar)
153
5,277
4,491
202
251
123
172
1,017
502
102
Legend
Country
Brazil
Canada
China
France
Germany
India
Russia
Spain
South Africa
United States
Data source: Ethanol Industry Outlook 2007, RFA
Map Not to Scale
April 2007
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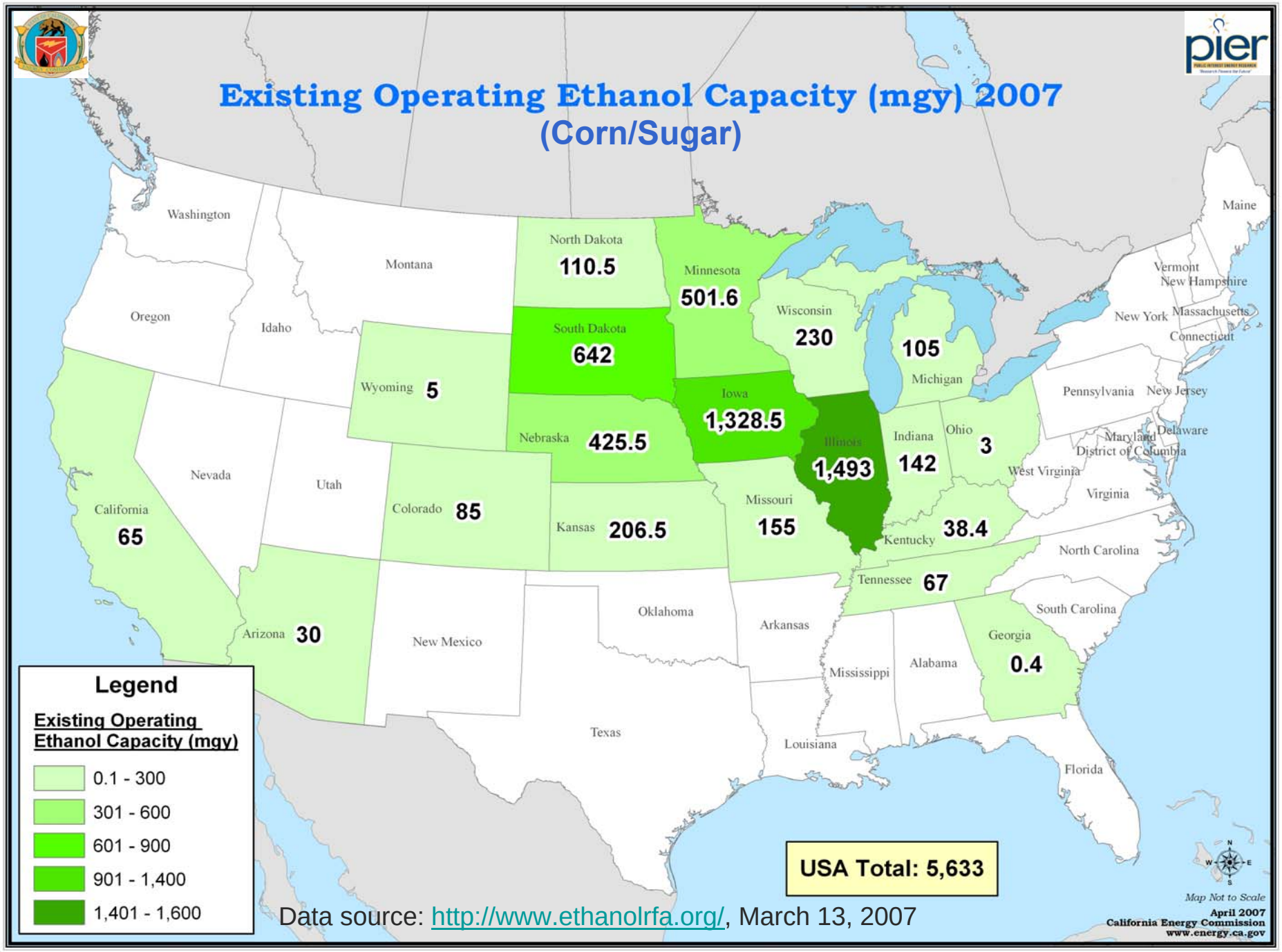
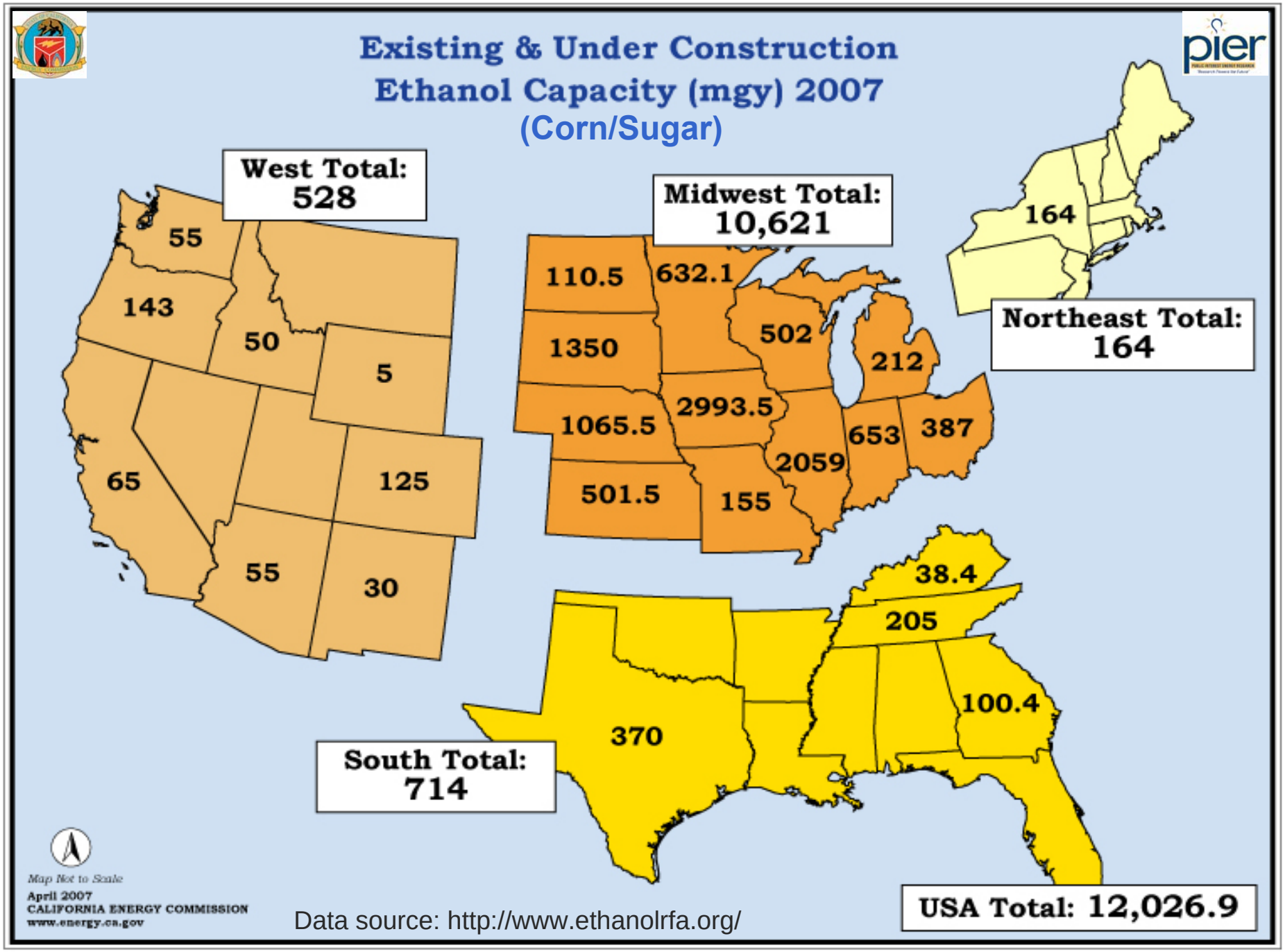


Data source: http://www.ethanolrfa.org/, March 13, 2007


Existing & Under Construction
Ethanol Capacity (mgy) 2007
(Corn/Sugar)
West Total:
528
55
143
50
5
65
125
55
30
Midwest Total:
10,621
110.5
632.1
502
1350
212
2993.5
1065.5
653
387
2059
501.5
155
164
Northeast Total:
164
38.4
205
370
100.4
South Total:
714
USA Total: 12,026.9
Map Not to Scale
April 2007
CALIFORNIA ENERGY COMMISSION
www.energy.ca.gov
Data source: http://www.ethanolrfa.org/


California
Existing Ethanol Plants
(Corn/Sugar)
CA Total: 68 MGY, 2007
Pacific Ethanol, Madera - 35 (MGY)
Phoenix Biofuels, Goshen - 25 (MGY)
Parallel Products, Rancho Cucamonga, 3 (MGY)
Golden Cheese, Corona - 5 (MGY)
Data source: http://www.ethanolrfa.org/
T:\Projects\Special Requests 2\Zhang _ Jessica\FILENAME Existing Ethanol Plants CA_A.mxd
SISKIYOU
MODOC
HUMBOLDT
TRINITY
SHASTA
LASSEN
TEHAMA
PLUMAS
BUTTE
GLENN
SIERRA
MENDOCINO
NEVADA
YUBA
COLUSA
LAKE
SUTTER
PLACER
EL DORADO
SONOMA
YOLO
NAPA
SACRAMENTO
AMADOR
ALPINE
SOLANO
CALAVERAS
TUOLUMNE
MARIN
CONTRA COSTA
SAN JOAQUIN
MONO
ALAMEDA
STANISLAUS
MARIPOSA
SAN MATEO
SANTA CLARA
MERCED
MADERA
SANTA CRUZ
FRESNO
SAN BENITO
INYO
TULARE
MONTEREY
KINGS
SAN LUIS OBISPO
KERN
SAN BERNARDINO
SANTA BARBARA
VENTURA
LOS ANGELES
RIVERSIDE
ORANGE
SAN DIEGO
IMPERIAL

Production Cost (Exclude Capital Cost) of Corn/Cheese Whey Ethanol and Gasoline

Feedstock		Production Cost ($/gallon)	By product credits
Cheese Whey		0.98	Excluding
Corn			
	at $2.0/bushel	1.74	Excluding
	at $2.5/bushel	1.88	Excluding
	at $3.2/bushel	2.13	Excluding
Motor Gasoline			
	at $15/barrel crude	0.62	Including
	at $20/barrel crude	0.74	Including
	at $30/barrel crude	0.94	Including
	at $60/barrel crude	1.57	Including

Reference: Agricultural Economic Report Number 607, USDA, Washington, D.C. March 1989.

Corn Ethanol Energy Use and Net Energy Value per Gallon without Co-product Energy Credits

Production Phase	Milling process (Btu/gallon)	
	Dry	Wet
Corn production	21,803	21,430
Corn transport	2,284	2,246
Ethanol conversion	48,772	54,239
Ethanol distribution	1,588	1,588
Total energy used	74,447	79,503

To meet President's 35 billion gallon ethanol target, 2.6 Quadrillion (10^{15}) Btu/yr total energy (fossil fuel) are needed assuming dry milling process.

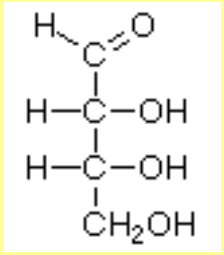
Data reference: The energy balance of corn ethanol: An update, USDA, July 2002.

Sugar / Starch vs LignoCellulose Feedstock

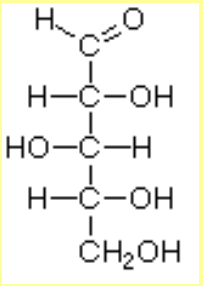
Sugars

- **1 Sugar**

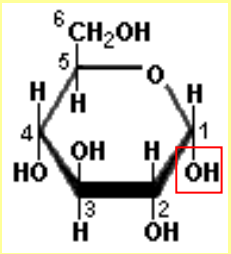
Tetroses (4 C) **Pentoses (5 C)** **Hexoses (6 C)** **Heptoses (7 C)**

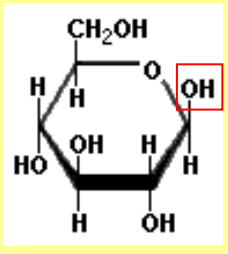


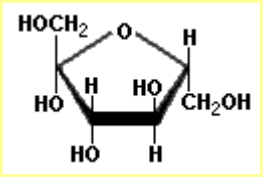
D-Erythrose



D-Xylose

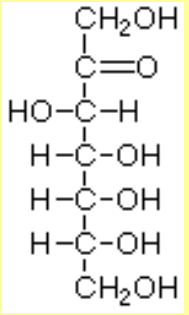






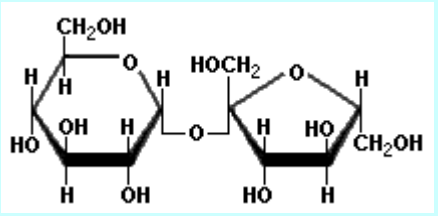
Fructose

α-D-Glucose β-D-Glucose

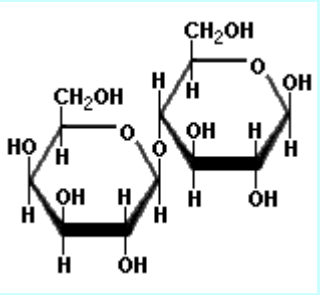


D-Sedoheptulose

- **2 Sugars**

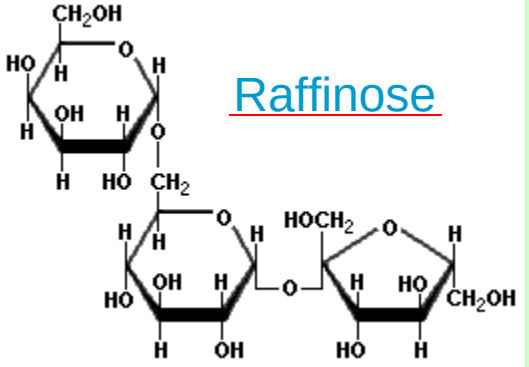


Sucrose



Lactose

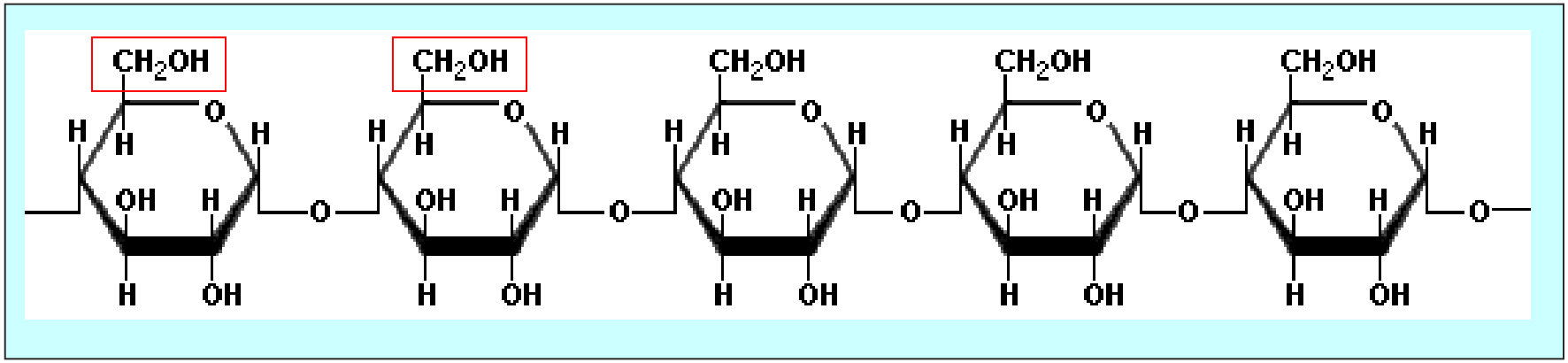
- **3 Sugars**



Raffinose

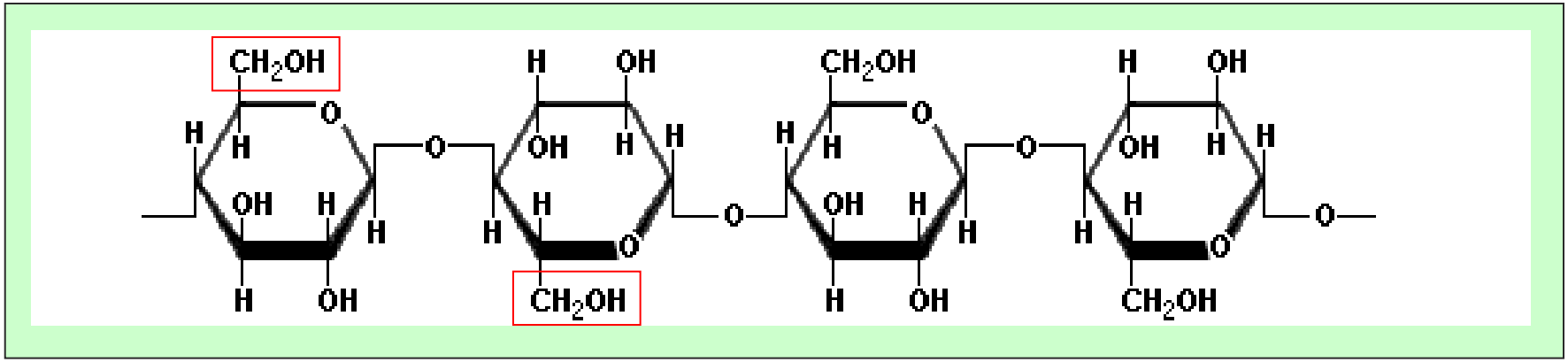
Starch and Cellulose

Starch is a polymer of α-D-Glucose (linear and branched)



Starch

Cellulose is a polymer of **β-D-Glucose (linear)**



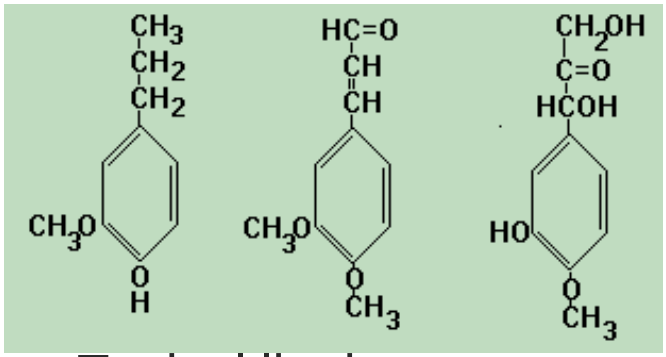
Cellulose

LignoCellulosic Biomass

(Linear)
Cellulose

(Branched)
Hemi-cellulose

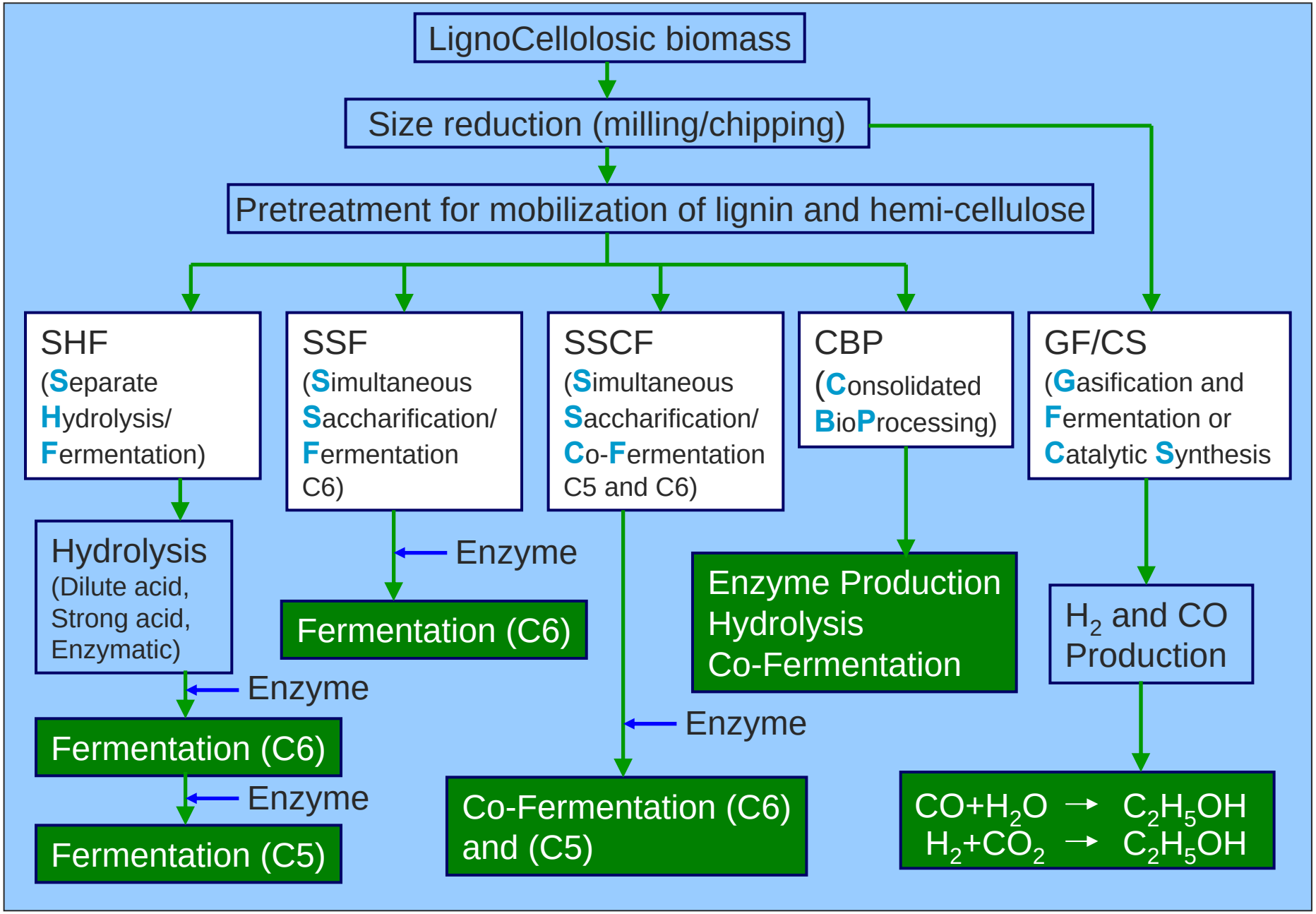
(Network)
Lignin



Typical lignin monomers

- Lignocellulosic biomass is composed of cellulose (40-60%), hemi-cellulose (20-40%), and lignin (10-25%).
- Lignin is composed of aromatic polymers which are not biodegradable.
- The steps of ethanol fermentation process using lignocellulosic biomass include
  - remove lignin
  - hydrolyze the cellulose and hemi-cellulose into simple C5 and C6 sugars
  - ferment simple sugars into ethanol

Conversion Pathways of LignoCellulosic Biomass to Ethanol



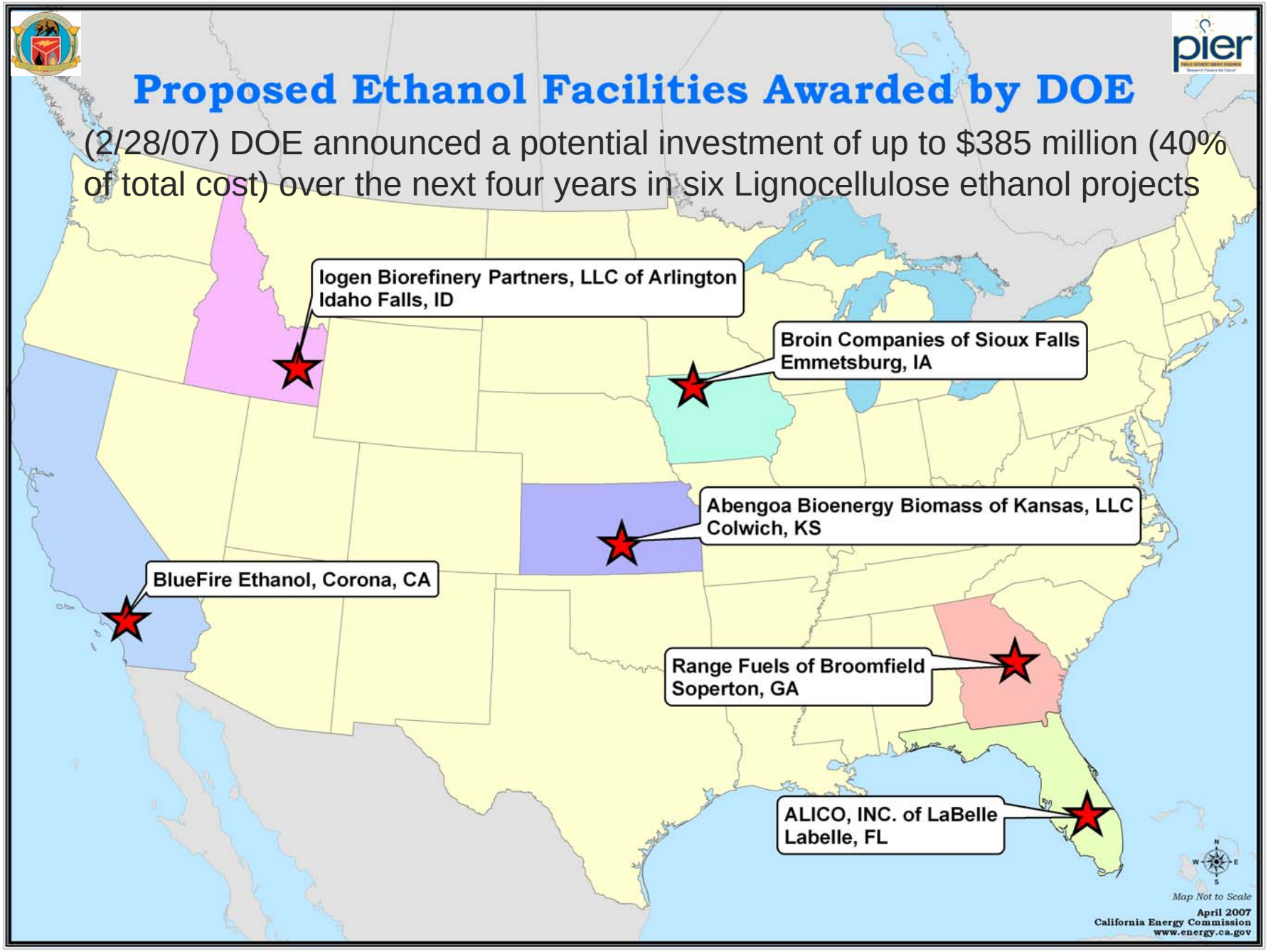
LignoCellulose Ethanol Technology Development
Companies Leading the Industry

- Abengoa http://www.abengoa.com/
- Archer Daniels Midland http://www.admworld.com/
- American Process, Inc. http://www.americanprocess.com/
- BRI Energy http://www.brienergy.com/
- BlueFire http://www.bluefireethanol.com/
- Borin http://www.poetenergy.com/broin/
- Celunol http://www.celunol.com/
- Ceres http://www.ceres-inc.com/
- Colusa http://www.colusabiomass.com/
- Diversa http://www.diversa.com/
- DuPont http://www2.dupont.com/
- Dyadic http://www.dyadic-group.com/wt/home
- Green Star Products Inc. http://www.greenstarusa.com/
- Iogen Crop http://www.iogen.ca/
- Range Fuels http://www.rangefuels.com/
- Lignol Energy Corp. http://www.lignol.ca/
- Mascoma http://www.mascoma.com/welcome/index.html
- Nova Fuels http://www.novafuels.com/
- Novozymes http://www.novozymes.com/
- Pure Energy http://www.pure-energy.com/pureindex.html
- SunOpta http://www.sunopta.com/bioprocess/
- Xethanol http://www.xethanol.com/

Reference: http://www.investincellulosicethanol.com/

Proposed Ethanol Facilities Awarded by DOE

(2/28/07) DOE announced a potential investment of up to $385 million (40% of total cost) over the next four years in six Lignocellulose ethanol projects



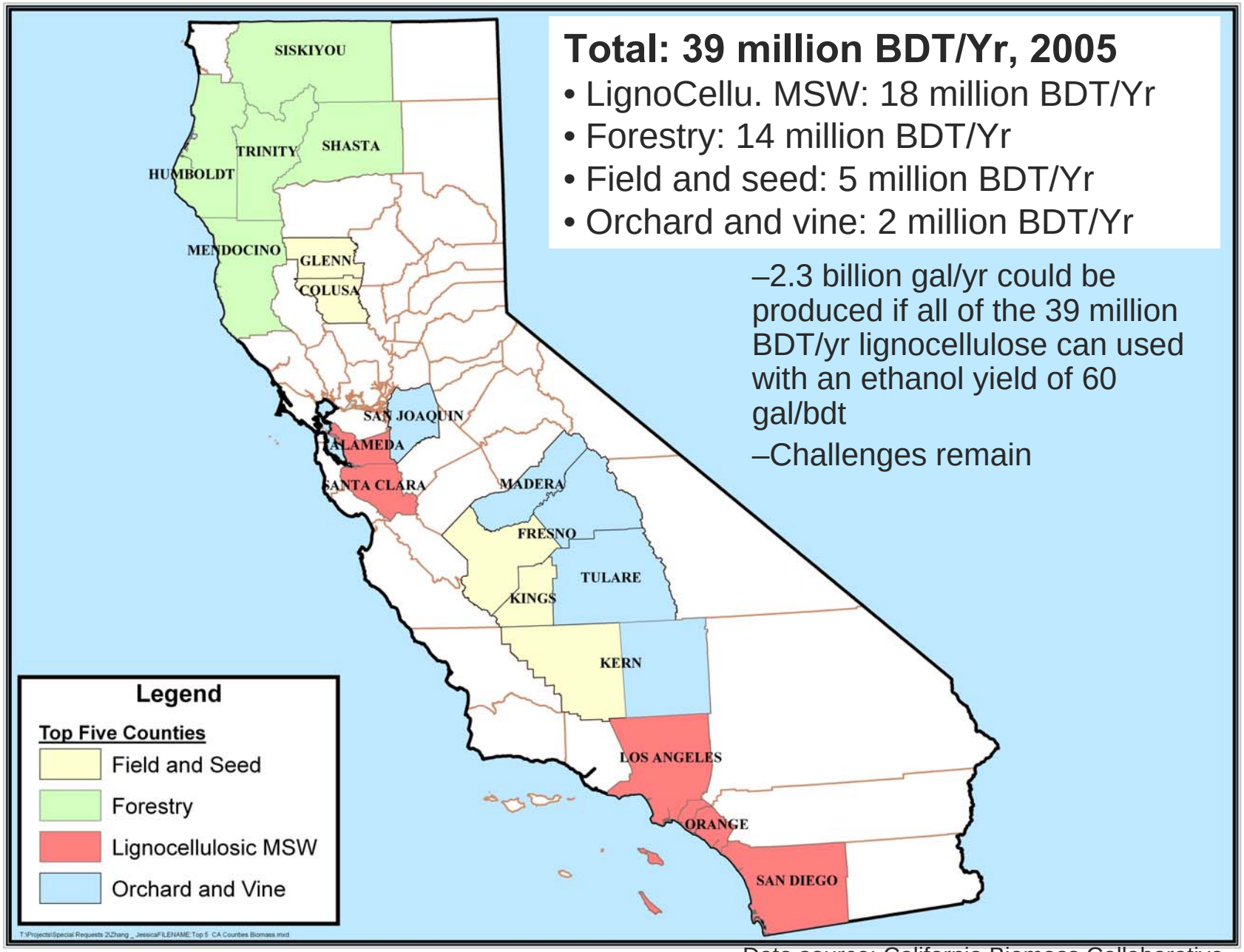
DOE Awards - Continued

Ethanol Projects	Feedstock	Technology	Ethanol Capacity (mgy)	Potential DOE Funds (million dollars)
Abengoa	Agricultural residues	SSF and GCS	11	76
Alico	Yard, wood, and citrus peel	GF	14	33
Bluefire	Green and wood wastes from landfill	SHF	24	40
Broin	Corn fiber and corn stover	SSF	26	80
Iogen	Wheat straw, barley straw, corn stover, switch grass, and rice straw	SSCF	18	80
Range Fuels	Wood residues and energy crops	GCS	40	76

Current Development of LignoCellulose Ethanol in California

- **Bluefire Ethanol**
  - Received $995,938 from California Energy Commission's PIER program on April 11, 2007 to develop and test a pre-commercial biorefinery system using green and wood wastes to produce ethanol
- **Technical Tasks** (to be performed under the PIER program)
  - Size of feedstock
  - Decrystallizer
  - Filterability
  - Acid recovery and sugar yield
  - Energy and cost of acid recovery
  - Dryer selection
  - Fermentation scale up and validation
  - Gypsum production

Outlook of LignoCellulosic Ethanol in California



Total: 39 million BDT/Yr, 2005

- LignoCellu. MSW: 18 million BDT/Yr
- Forestry: 14 million BDT/Yr
- Field and seed: 5 million BDT/Yr
- Orchard and vine: 2 million BDT/Yr

–2.3 billion gal/yr could be produced if all of the 39 million BDT/yr lignocellulose can used with an ethanol yield of 60 gal/bdt

–Challenges remain

Data source: California Biomass Collaborative

Challenges of LignoCellulose Ethanol

- Dilute and Strong Acid Hydrolysis (SHF)
  - The need to regenerate acids
  - Formation of inorganic waste streams
  - High operational temperatures and pressures
  - The corrosiveness of the pretreatment
  - High water consumption: 28-54 gallon water/ gallon lignoCellulose ethanol produced vs 15 gallon water/gallon corn ethanol produced
- SSF, SSCF, and CBP
  - Effective enzymes to separate lignin from cellulose and hemicellulose
  - Effective enzymes to simultaneously hydrolyze cellulose and hemi-cellulose into simple C5 and C6 sugars
- GF/CS
  - Feedstock homogeneity (moisture and composition)
  - Capital cost
  - Tar formation
  - Syngas cleanup

Conclusions

- While technologies to convert lignocellulosic biomass to ethanol currently exist, they still need to demonstrate economic and financial feasibility
- At this moment, there is no integrated commercial plant anywhere around the world producing ethanol from lignocellulosic biomass
- Strong and weak acid hydrolysis and steam pretreatment still suffer from major drawbacks
- Fundamental researches (laboratory) are still needed on effective enzymes, fungi, and/or bacteria working on lignocellulosic biomass
- Fundamental data including material and energy balances using lignocellulose are still needed to validate the existing integrated pilot-scale results
- California has 39 million BDT/yr lignocellulosic biomass that could be used to produce lignocellulose ethanol when commercial technology is brought into the market