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Recent development and perspectives of biobutanol production

Jieun Lee

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Sungkyunkwan University
School of life science and biotechnology

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Overview

- Urgent needs for alternative energy
- Butanol as an alternative energy for transportation
- Butanol production
- Recent development in butanol research
- Perspectives of butanol production using algae
- Summary

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Background

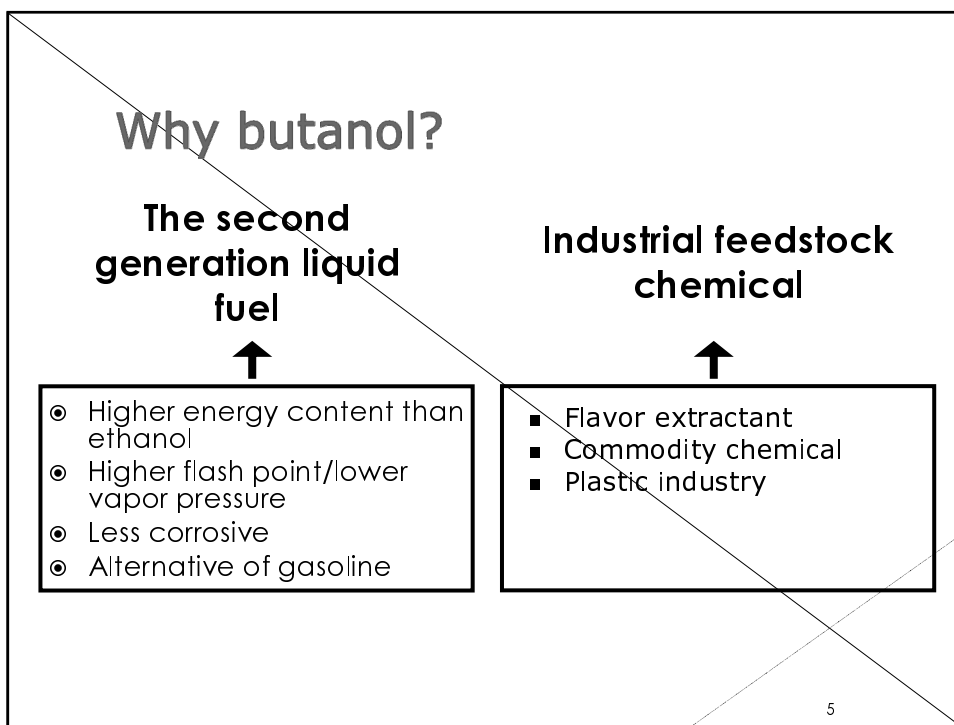
- Limitation of fossil fuels
- Increasing oil price (\$150/ Barrel, May, 2008)
- Concerns of environment
 - > Kyoto protocol
- Energy security
 - > Competition in development of energy
- Initiation of energy projects
 - > 저탄소 녹색성장

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Bioenergy

- Wind, tide, wave, solar, geothermal energy
 - > Electricity
- More energy needed?
- Alternatives for gasoline
 - > portable
 - > Reduction of CO₂ emission
 - > Price competitiveness
 - > ethanol, butanol, diesel

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Butanol as a fuel

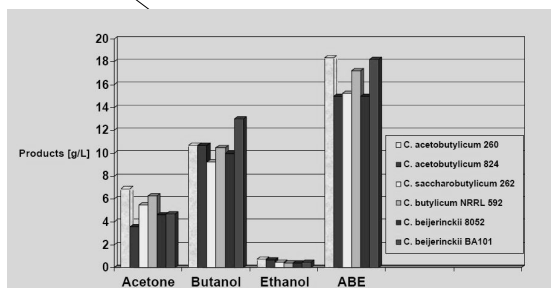
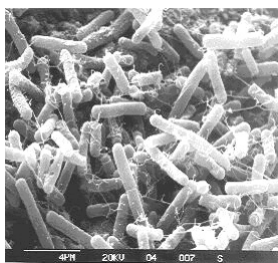
	Methanol CH ₃ OH	Ethanol C ₂ H ₅ OH	Butanol C ₄ H ₉ OH	Gasoline Many CH
Energy content (Btu/gal)	63K	78K	110K	115K
Vapor pressure @ 100F (psi)	4.6	2.0	0.33	4.5
Motor Octane	91	92	94	96
Air: fuel ratio	6.6	9	11.1	12-15

- ⊙ Performance of butanol as an alternative of gasoline

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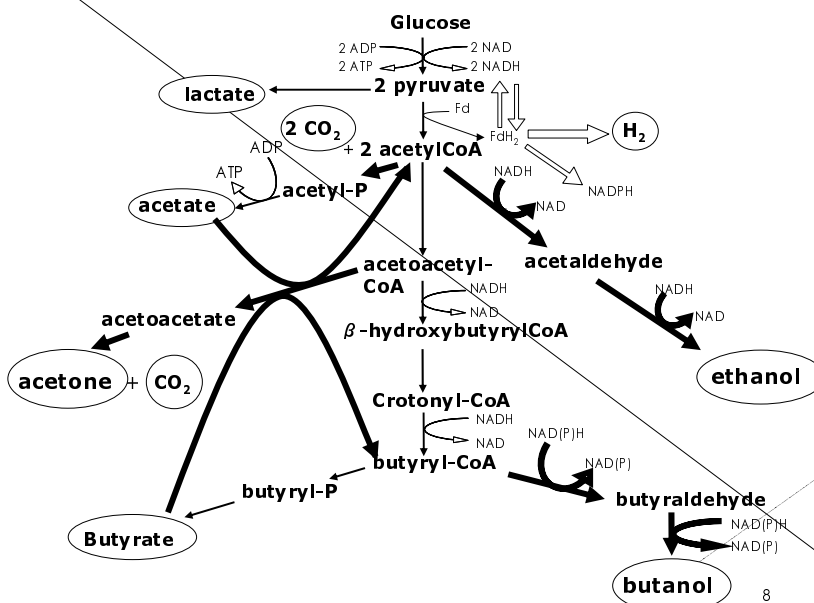
Butanol production by solventogenic clostridia

- ◉ ABE fermentation
 - > History
 - > Physiology
 - > Products
- ◉ Strains in research and industry



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ABE Fermentation Pathway



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Butanol production = Biorefinery

◉ Development of biorefinery infrastructure

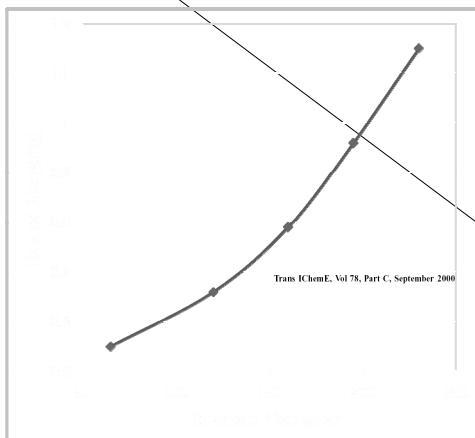
- > Production of
 - 4 carbon backbone-chemicals:
 - Organic acids
 - Ethanol
 - Hydrogen
 - Riboflavin
 - Extracellular enzymes

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ABE Fermentation using different sugars

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Economics in butanol production



Fossil Fuels	Date	Market Price	\$/MMBTU
Crude oil	9/26/08	\$106.77 \$/Barrel	\$18.41
Gasoline	9/29/08	\$3.632 \$/Gallon	\$29.06
Diesel Fuel	9/29/08	\$3.959 \$/Gallon	\$30.76
Natural gas	10/1/08	\$7.76 \$/MMBtu	\$7.76
Liquid Propane (Gulf)	9/26/08	\$1.52 \$/Gallon	\$16.59
Heating oil	9/26/08	\$2.996 \$/Gallon	\$21.71
Electricity retail, resid.	Feb-08	10.24 ¢/kWh	\$30.01
Coal	9/26/08	\$84.00 \$/ton	\$3.56
Liquid Fuels			
Ethanol (Iowa)	10/3/08	\$2.05 \$/Gallon	\$26.97
biodiesel (Iowa)	10/3/08	\$4.26 \$/Gallon	\$36.10
Soybean oil (Central IL)	10/3/08	41.93 ¢/Lb	\$24.66
No 2, Yellow grease	10/3/08	\$27.50 \$/cwt	\$17.86
Solid Fuels			
Fuel pellets	10/3/08	\$280.50 \$/Ton	\$17.53
Shelled corn	10/3/08	\$4.17 \$/Bushel	\$9.14
Compost	10/3/08	\$25.00 \$/cu. yard	\$3.63
Wheat straw	10/3/08	\$105.00 \$/Ton	\$7.09
Grass hay (lg md bale)	5/15/08	\$80.00 \$/Ton	\$5.33
DDGS	9/30/08	\$132.50 \$/Ton	\$7.05

Note: Federal electrical price data have not been updated. Public hay and straw prices are not changing through the summer.

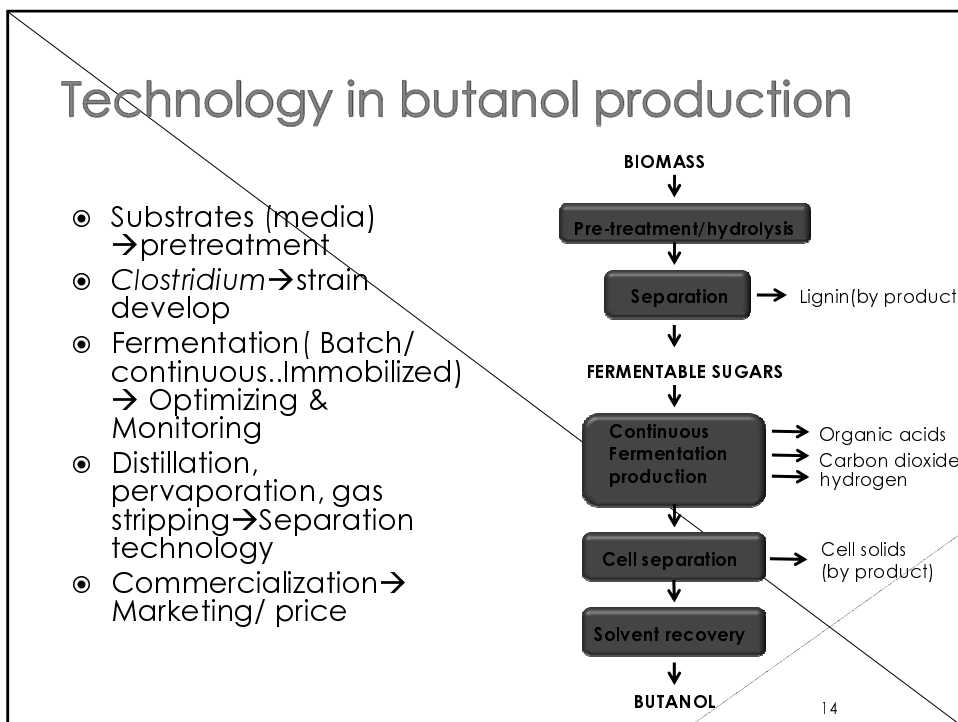
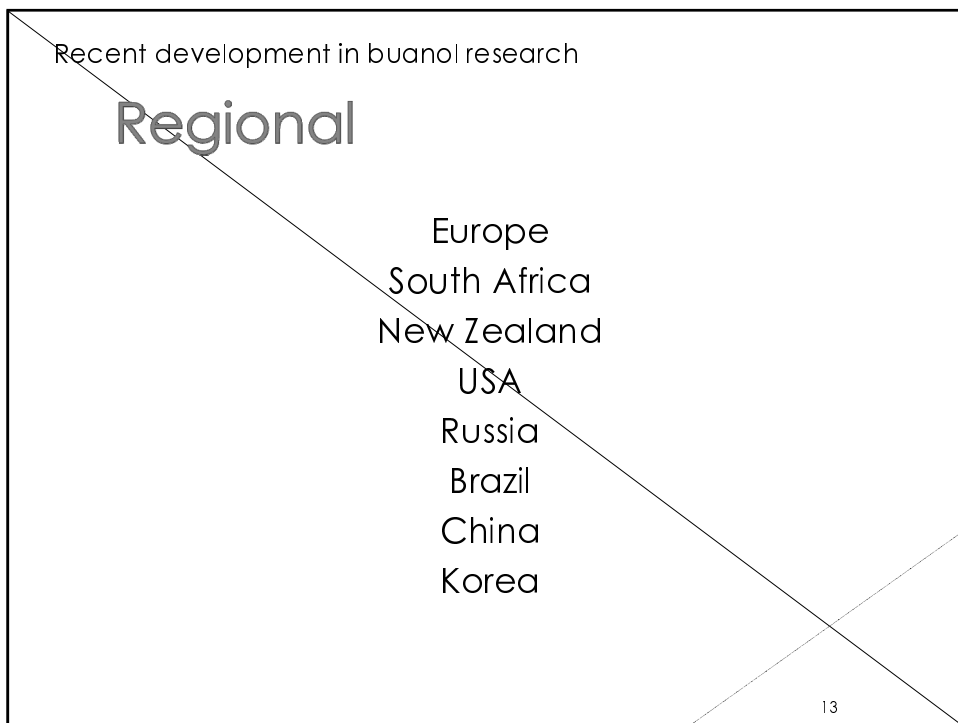
- Effect of substrate price on butanol price (ABE yield= 0.42)

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Recent development in butanol research -part 1. World-

Regional development
Progress in academia
Progress in commercialization

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Substrates

- Traditional
- Candidates
- Substrates in use

- Production of hydrolyzates

Substrates	Main Carbohydrates	Upstream processing steps
Corn/ Degermed Corn	Starch 71%	Dry/wet milling Dilution & sedimentation Cooking-mashing Steam explosion & hydrolysis Enzyme treatment
Molasses	Sucrose 50%	
Whey Permeate	Lactose 4-5%, Mineral	
Soy Molasses	Oligosaccharides 43%	
Jerusalem Artichokes Potatoes	Inulin Starch	
Agricultural Wastes	Hemicellulose, lignocellulose: Corn stover, straw, grass	

A wide spectrum of substrates, resistance to inhibitors, complete utilization of substrates are required for desired strains!!

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Use of renewable substrates for butanol production:

Rice bran, rice water, wood hydrolyzates

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Research in Strain development

- Mutagenesis:
 - > *C. beijerinckii* BA101
- Recombinant strains:
 - > *C. acetobutylicum* ATCC 824
 - > *E. coli*
- Targets to develop better strains
- Tools for metabolic engineering

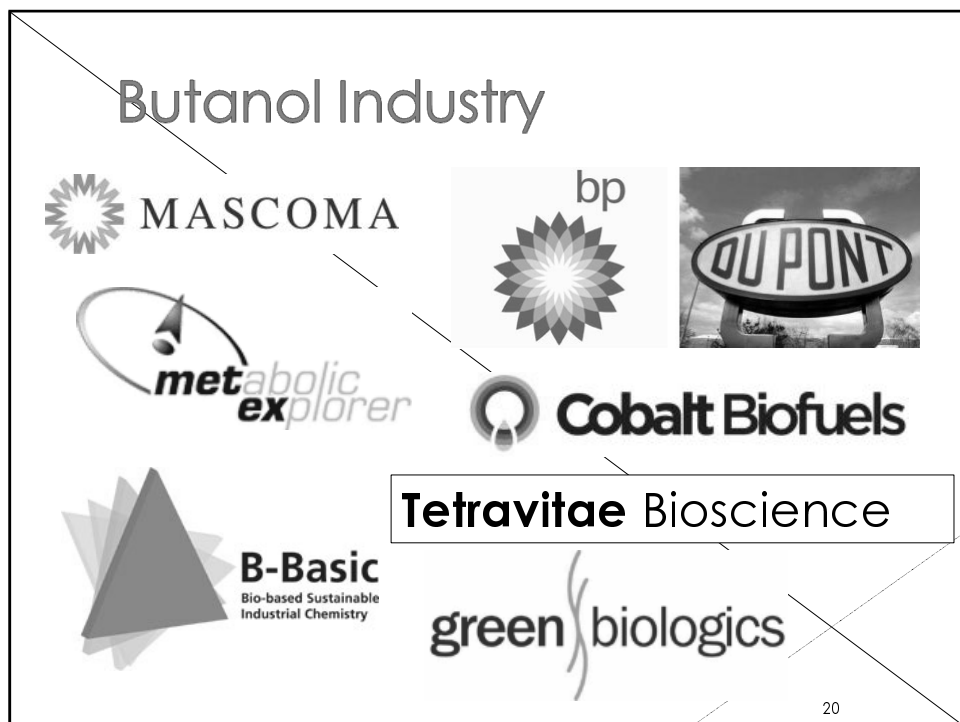
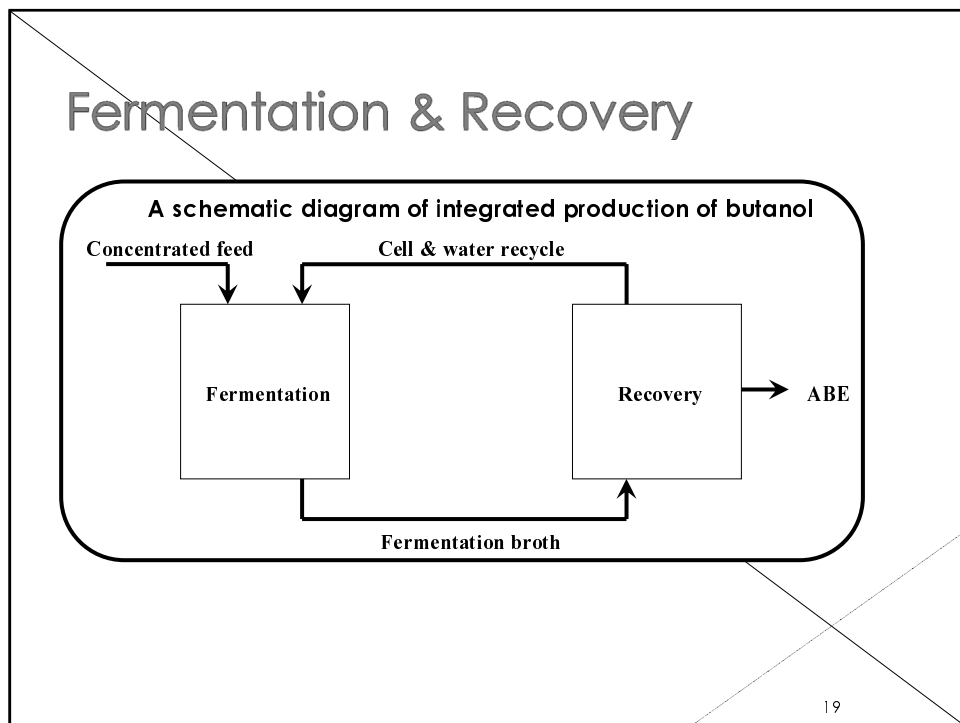
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Mutagenesis

- High butanol production
- Wide spectrum of substrates
- Complete utilization of substrates
- Resistance

Solventogenic Clostridia should be a platform for metabolic engineering!

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Limitations and perspectives of butanol production

- ◎ Research in Clostridium :
 - > a limited society → collaboration
- ◎ Source and supply of substrates
 - > Sugarcane → a variety of substrates
- ◎ Price competitiveness in market
 - > Commodity Chemical → Fuel

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Clostridium 10 at Wageningen, Netherland



mic meeting since

entogenic clostridia



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Recent development in butanol research II - Part 2. Korea -

Background
Recent development
Limitations and perspectives


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Background

- Urgent needs of sustainable/ renewable alternative energy
- Belated initiation of bioenergy
- 저탄소녹색성장- 해양바이오에너지 (2008. 8. 15)
- Traditionally strong background in fermentation
- Recent development in butanol research
 - > Interest in butanol production
 - > Few research groups
 - > 3rd generation substrate: Algae

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Algae as a substrate for butanol production

Substrates	Starch-based	lignocellulosics	Red algae
Carbohydrate contents	Starch	Cellulose, hemicellulose, lignin	Glucan (20%) & galactan (60%)
Harvest cycle		4-6 times/yr	4-6 times/yr
CO ₂ fixation		5-10 ton/h	5-10 ton/h
Hydrolyzate properties		Glucose and galactose	Glucose and galactose
Disadvantages	Enzymatic problem	Enzymes, etc....	None
Cultivation	Land, water, Fertilizer	Land, water, Fertilizer	Unlimited: Sea

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Biobutanol production using red algae

- Algae as the 3rd generation of substrates
- A newer is a better competitiveness!!
- Selection of red algae:
 - > high in glucan, nutrient & minerals
 - > low in galactan and protein
- Problem of accumulation of residual sugar (galactose)
- Metabolic engineering for efficient galactose metabolism
- Fermentation inhibitors produced during pretreatment

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Limitation and perspectives of biobutanol production in Korea

- ◉ Lack of fundamental research and expert → available high quality labor
- ◉ 정부 주관하의 장기적 원천기술개발 계획수립
- ◉ 범부처간의 시스템 구축 및 제도적 지원 (면세, 지원금 등)
- ◉ Relationship with Clostridium society
- ◉ 외국 기술 도입/우량기업/연구소 (coordinator)
- ◉ International collaboration- university (인력)

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Summary

- ◉ **Butanol** is prior to ethanol
- ◉ Use of **Clostridium** as a platform
- ◉ Use of superior substrates: **algae**
- ◉ Plans for short terms and long terms
 - > Production of commodity chemical (S), market
 - > Biobutanol production (L), labor, strain development
- ◉ **Collaboration** with international research group
- ◉ Purchase of license and foreign technology
- ◉ <정부-기업-연구> 체제 구축
 - > Advisory board for consulting and coordination

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