



Process
Economics
Program

Process Economics of Biodegradable Polymers from Plants



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- **Introduction**
 - **Commercial PHAs and Developments**
- **Metabolic Pathways**
- **Plants of Interest**
 - **Oilseed Processing**
- **PHAs from Crops**
 - **Oilseed Crops versus Switchgrass**
- **PHAs by Fermentation**
- **Process Economics**
- **Other Barriers**

Polyhydroxyalkanoate

Side Chain

Polyhydroxybutyrate (PHB)	-CH₃
Polyhydroxyvalerate (PHV)	-CH₂CH₃
PHBV (Biopol)	-CH₃ and -CH₂CH₃
PHBHx (Kaneka)	-CH₃ and -CH₂CH₂CH₃
PHBO (Nodax™)	-CH₃ and -(CH₂)₄CH₃
PHBOd	-CH₃ and -(CH₂)₁₄CH₃

➤ **ICI/Zeneca/Monsanto**

- **Commercial production of Biopol ceased in 1999**

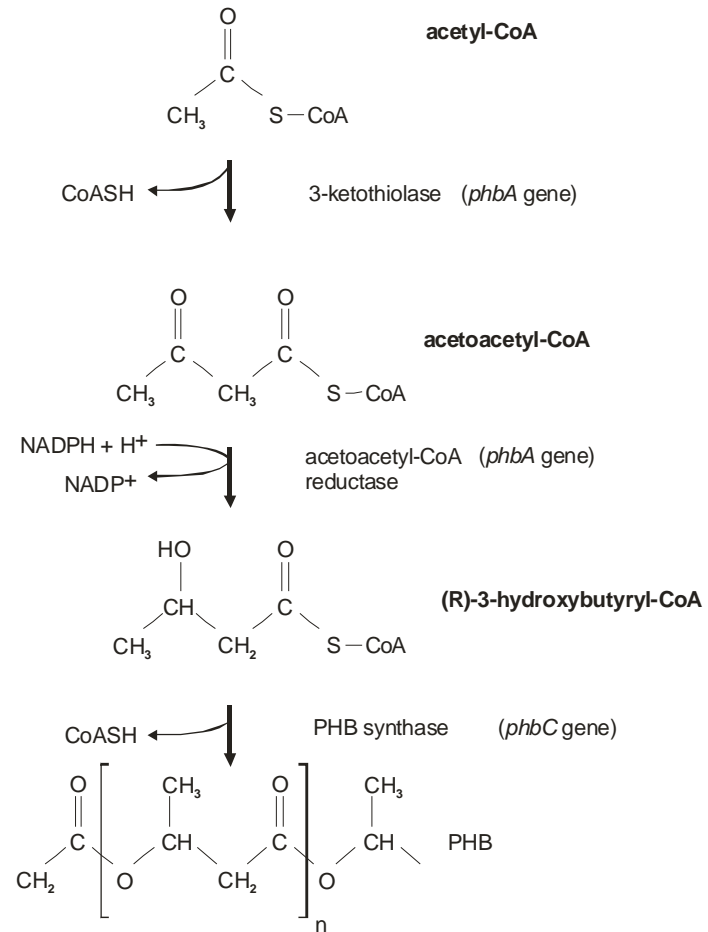
➤ **Metabolix**

- **Acquired Monsanto Biopol technology in 2001**
- **Toll fermentation production 2002**
- **DOE funding for development of production in plants**
- **Collaborative agreement with BASF 2003**

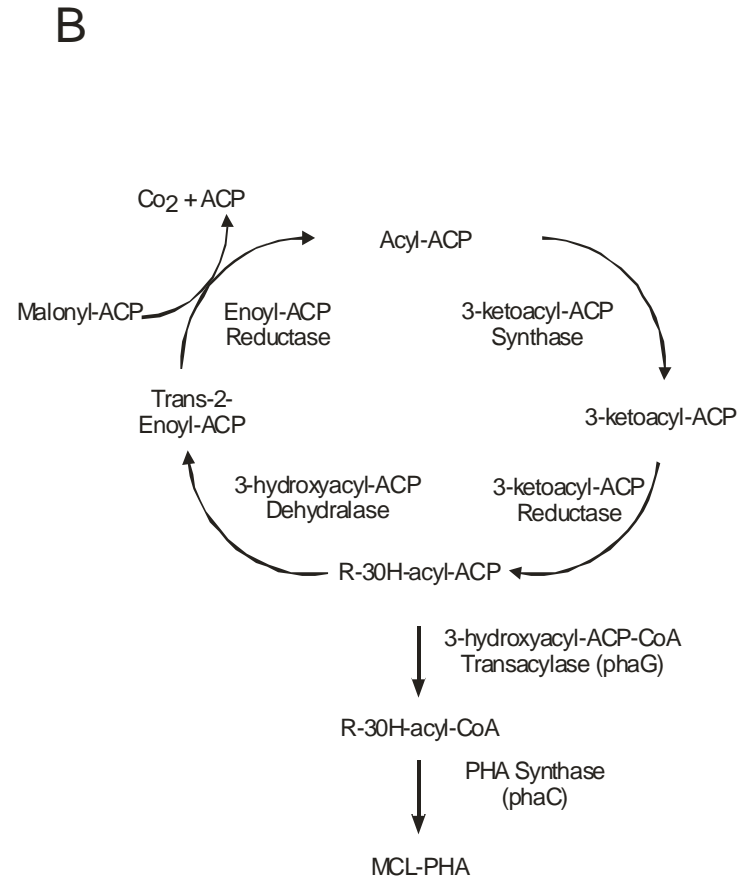
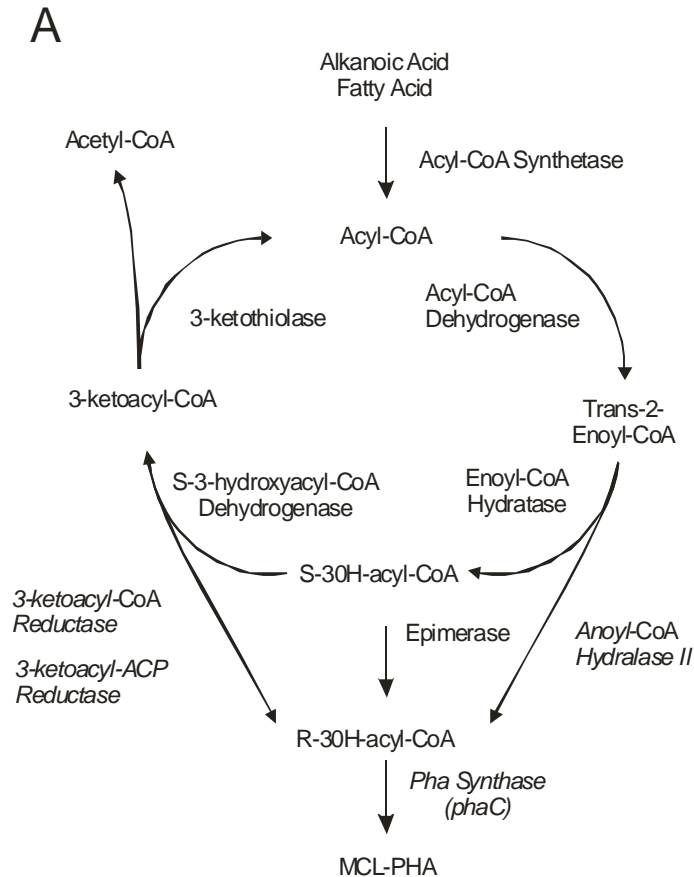
➤ **Procter & Gamble**

- **License Nodax to Kaneka for production in 2005**

- **Over 40 Bacteria Synthesizing PHAs**
 - **Short chain length PHAs,
e.g. *Ralstonia eutropha***
 - **Medium chain length PHAs,
e.g. Pseudomonads**
- **Key Pathway Attributes**
 - **Acetyl-CoA as substrate**
 - **PHA synthase as key enzyme**

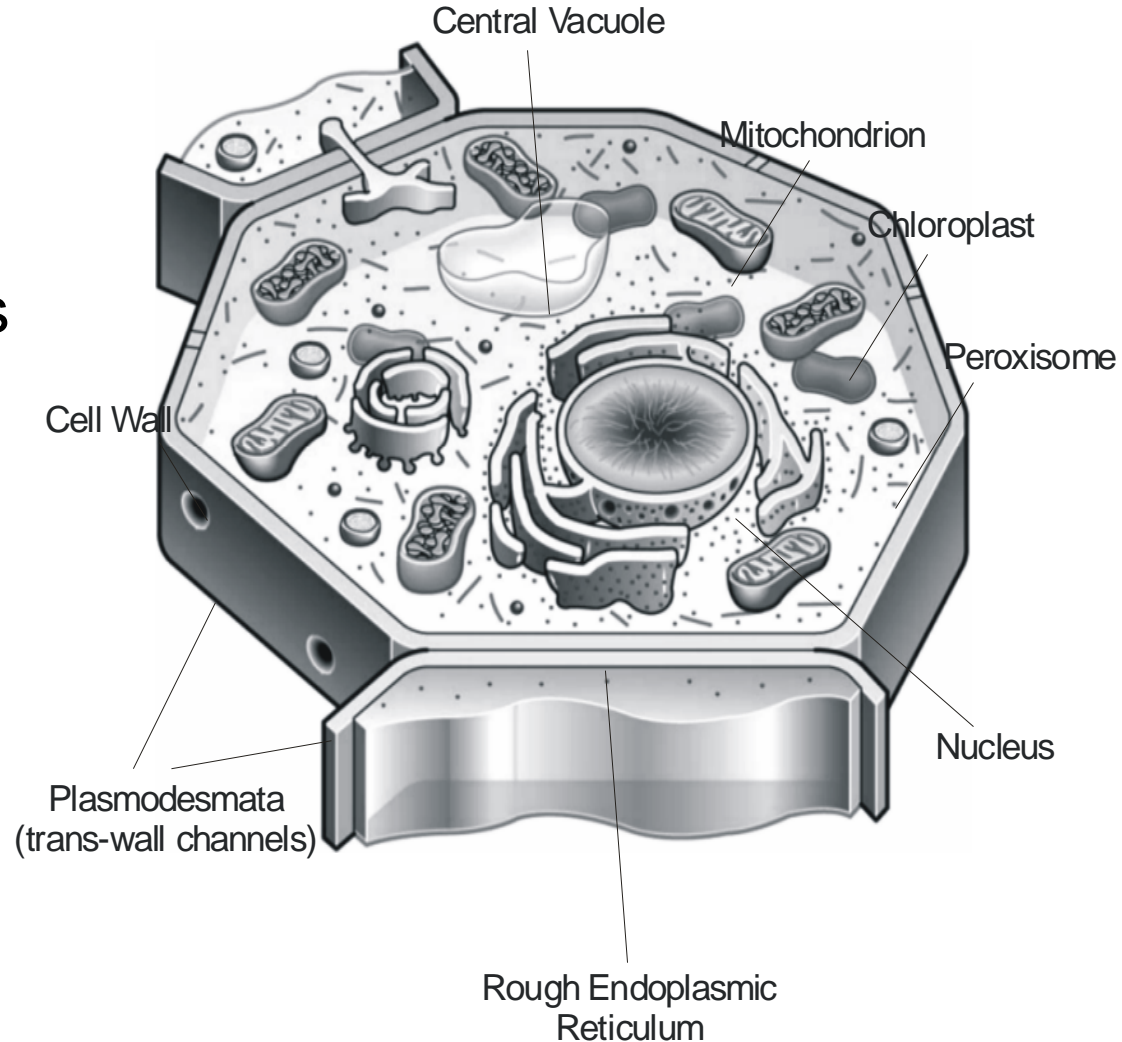


Source: US 5,610,041



PHA Synthesis

- cytoplasm
- plastid
- peroxisome



➤ **Oilseed Crops**

➤ *Arabidopsis thaliana*

➤ **Corn**

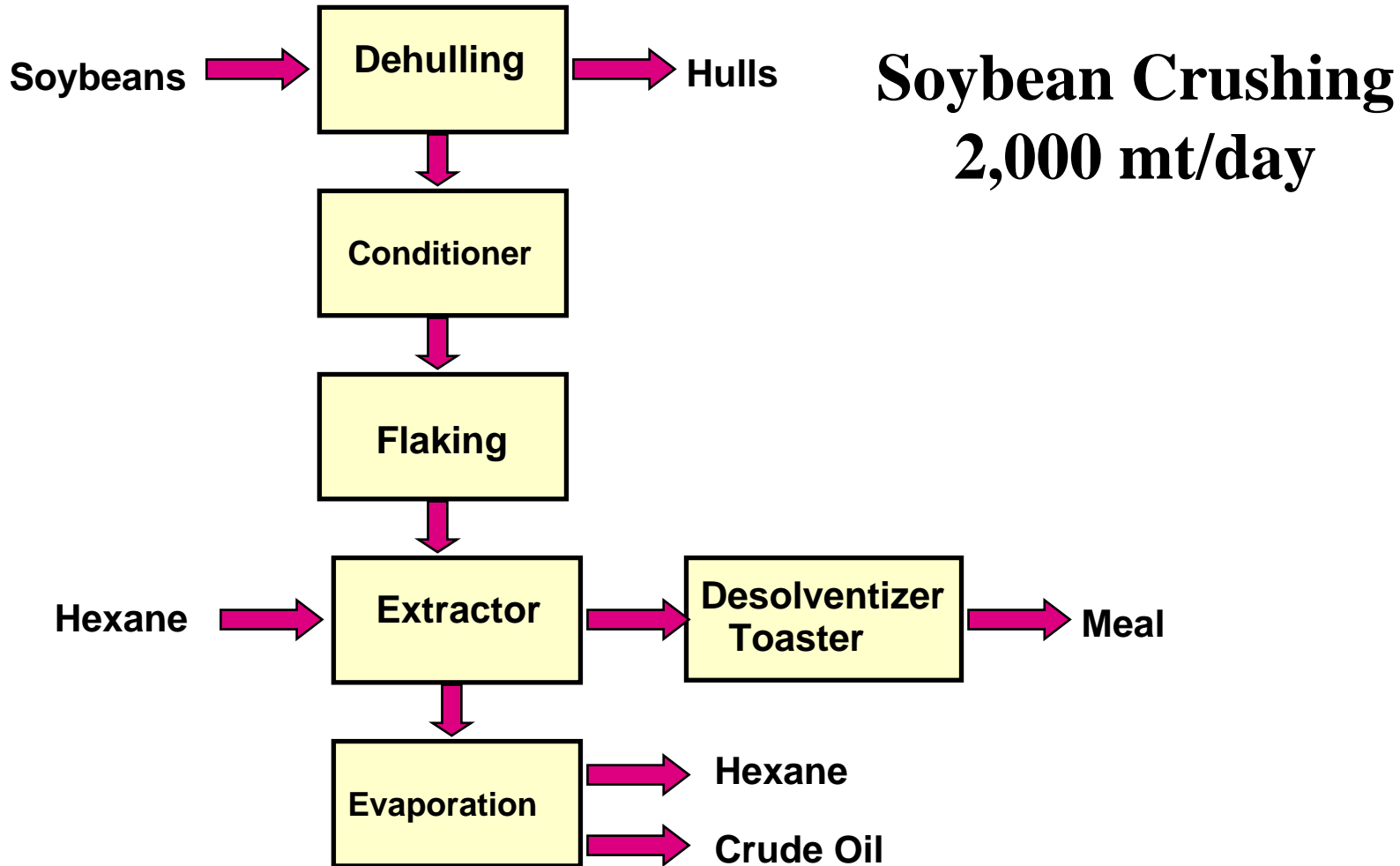
➤ **Rapeseed/Canola**

➤ **Soybean**

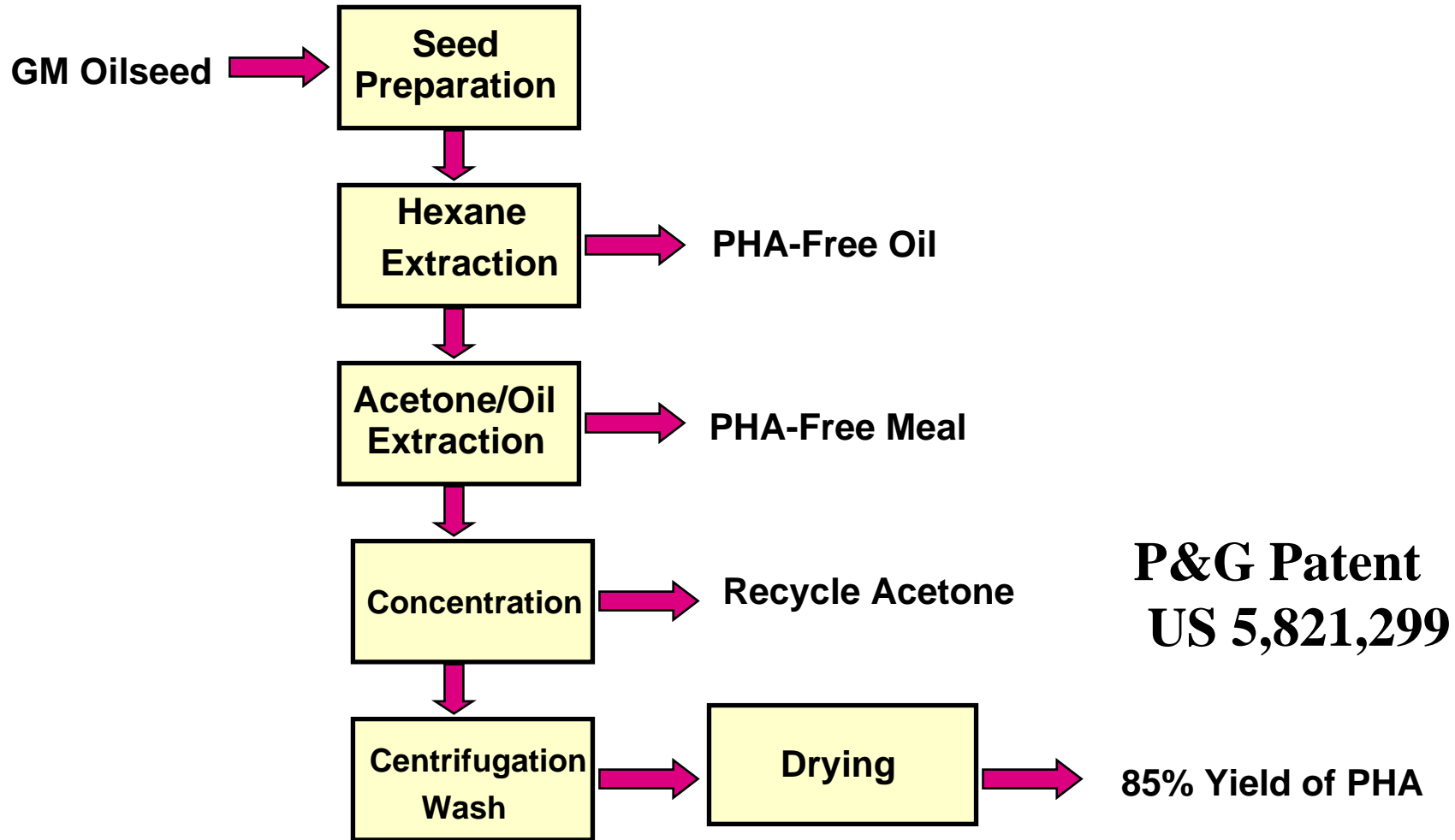
➤ **Other**

➤ **Cotton (in fiber), Potato, Tobacco**

➤ **Switchgrass (DOE energy crop)**



PHA from Oilseed Crops



Oilseed Crops vs Switchgrass

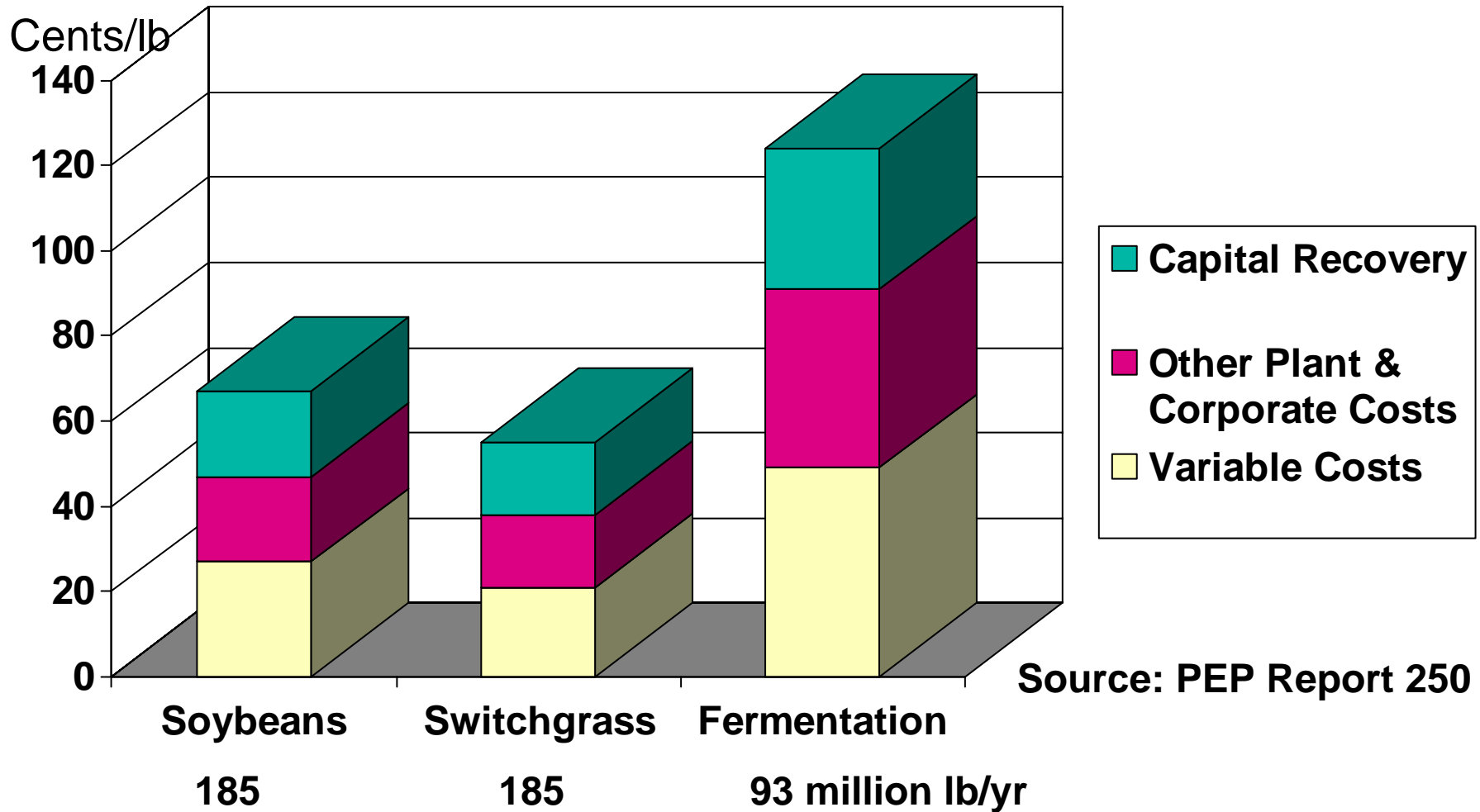
	Soybean	Switchgrass
Existing Infrastructure	145,000 tons/day U.S. crushing capacity	None
Recovery Process	Solvent extraction with oil and meal recovery	Solvent extraction with no oil recovery
Feedstock Cost	\$5.60/bushel (\$214/ton) includes premium	\$30-40/ton excluding transportation
Coproducts	Oil and meal	Fuel for steam and electricity

➤ **Zeneca Process**

- **Glucose and propionic acid carbon substrates**
- **Aqueous recovery using enzyme permeabilization**
- **Production costs >\$4/lb (PEP Report 115C)**

➤ **Process Improvements**

- **Bacteria strains with higher yield and productivity, e.g. recombinant *E. coli***
- **Alternative carbon substrates, e.g. polyols**
- **Recovery simplifications, e.g. diafiltration with organic solvent**



	<u>Soybeans</u>	<u>Switchgrass</u>
Total Fixed Capital	\$143.8 mil.	\$119.7 mil.
Raw Materials	84	20
By-Products	-65 (meal and oil)	0
Utilities	8	8
Other Plant Costs	13	10
Plant Gate Costs	40¢/lb	38¢/lb

- **Crop Identity Preservation**
 - **Premium to farmers and handlers**
 - **Segregation by grade**
- **Public Opinion of Biotech Crops**
 - **Political**
 - **Constraining regulations**

Description	Acres Grown	Premium, \$/bushel
Non-GMO	14 million	0.25-0.5
High Isoflavone	12,000	0.55
Low Saturated Fat	11,000	0.3
High Sucrose	4,500	0.9
High Protein	Several thousand	0.35-1.25
High Oleic	Several thousand	0.6
Low Linolenic	2,000	0.35

Crops Worst for Confining Genes:

- **Routinely breeds with related crops**
- **Produces large amounts of pollen and seed**
- **Serves as an important food and feed crop**
- **Spontaneously mates with wild relatives**
- **Widely planted throughout the world**

- **Large Barriers to Commercialization**
 - Identity preservation
 - Managing public opinion
 - Technology development (5-10 years away)
- **Preferred Process Depends on Scale**
 - Medium volume, multiple grades: fermentation
 - Large volume, few grades: bioengineered crops