Session on:
Direct Conversion of Methane to Higher Value Products Using Biological Systems

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World Congress
On
Industrial Biotechnology

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Montréal

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“Nature’s first green is gold”

from: Nothing Gold Can Stay, Robert Frost

Started November 23, 2011

Portfolio company of Warburg Pincus

$355 million, early-stage investment company

Focused on the carbon value-chain

- Renewable carbon technology (green)
- Environmental/cleantech related to fossil carbon (black)
- Hybrid technologies (green-black)

North American focus

10 seed/early-stage deals, initial investments between $500,000 and $10 million

Ability to do large follow-on investments for capital intensive

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The opportunity

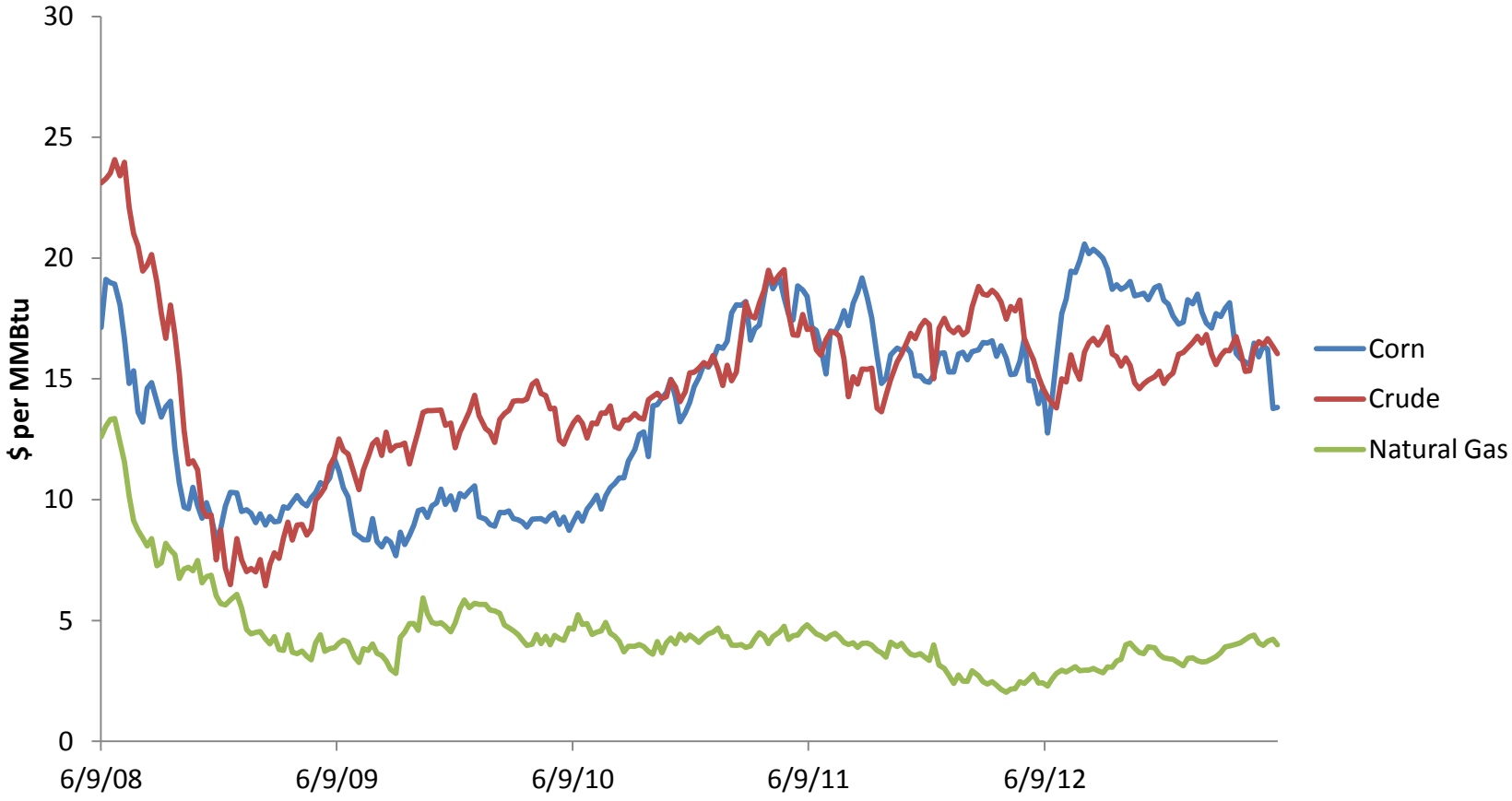
Some challenges

A quick case study

“The best way to predict the future is to invent it.”
(Alan Kay, 1971 meeting at PARC, Palo Alto Research Center)

"Those who cannot remember the past are condemned to repeat it."
George Santayana, 1924

Relative Cost Advantage of Natural Gas



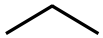
Source: CRB
Notes: CBOT corn, WTI crude, Henry Hub natural gas

Natural Gas

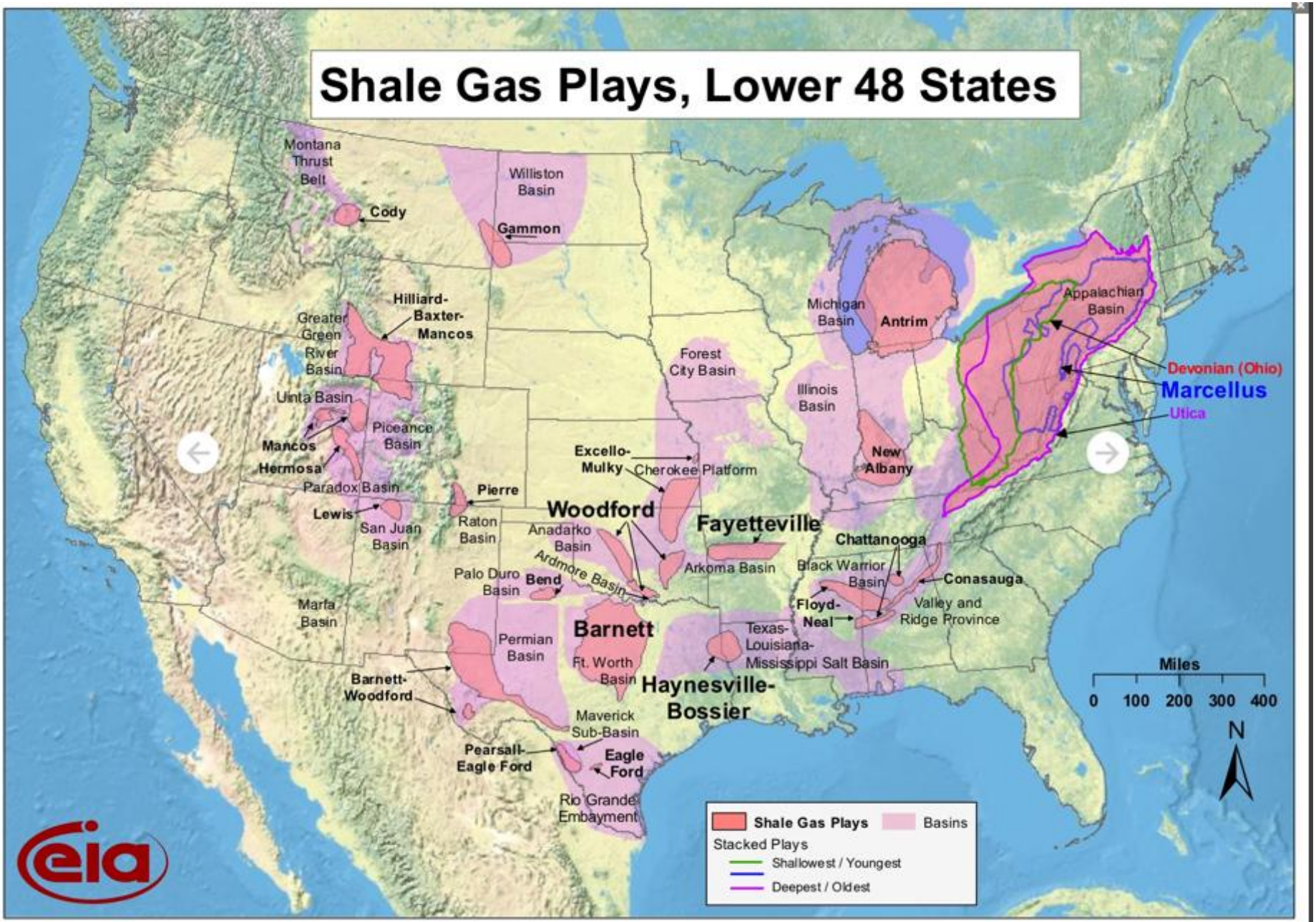
"Dry gas" is primarily methane

"Wet gas" contains a significant amount of "natural gas liquids"

ethane 

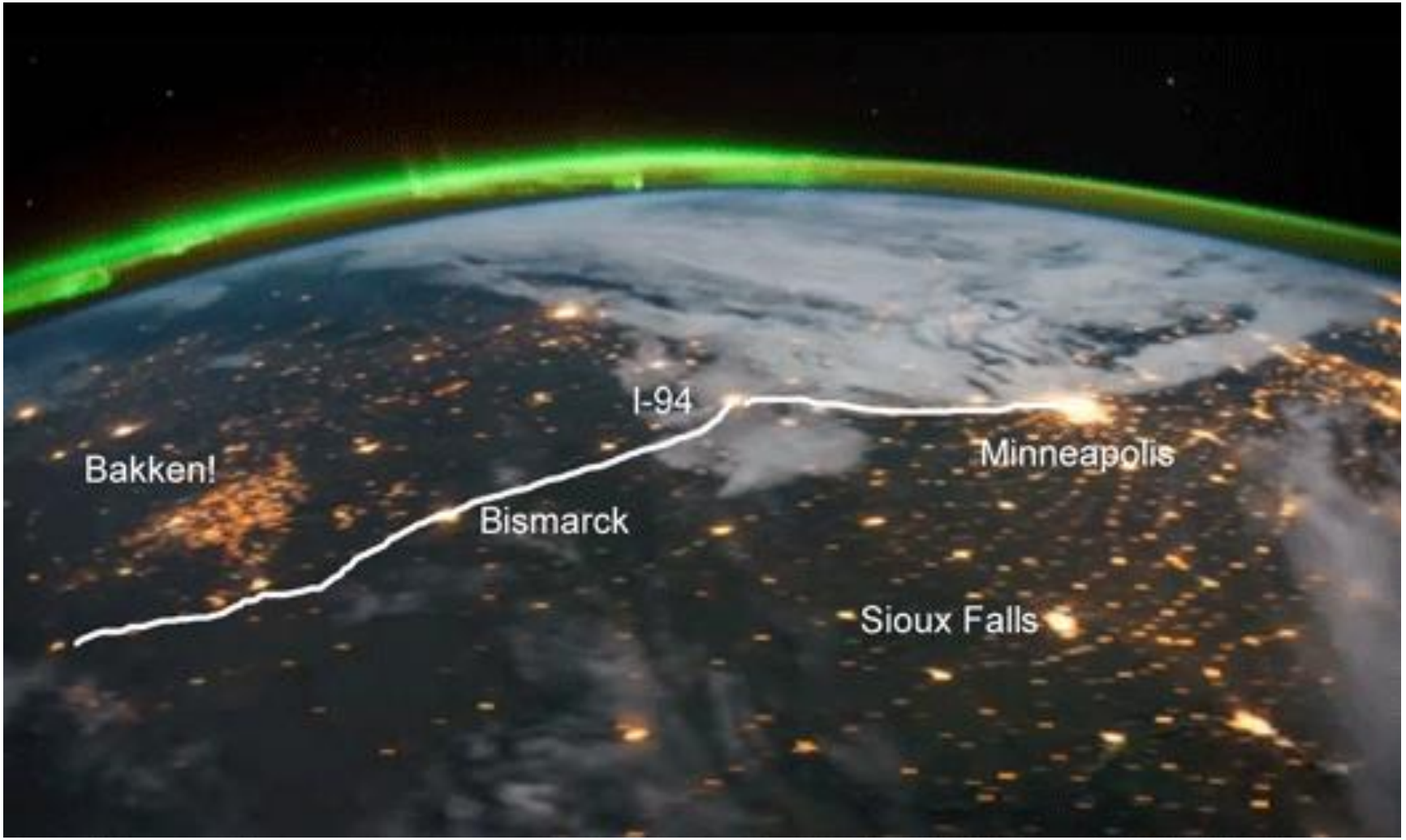
propane 

butane 



Source: Energy Information Administration based on data from various published studies.
Updated: March 10, 2010

Stranded, flared methane



Renewable sources of methane?

$C_6H_{12}O_6$ ---> 3 CH_4 + 3 CO_2

Y = 0.27 pounds of product per pound of feedstock

Yield is low, but good waste feedstocks


Operational Biogas Systems in the U.S. -
Agricultural, Landfill, and Wastewater Systems Only
Newfoundland and Labrador
Quebec
Gulf of St Lawrence
Vancouver
Winnipeg
Montana
North Dakota
South Dakota
Wyoming
Nebraska
Nevada
Utah
Colorado
Arizona
New Mexico
San Diego
Phoenix
Texas
San Antonio
Gulf of California
Monterrey
Gulf of Mexico
Mexico
Guadalajara
Mexico City
Havana
Cuba
Dominican Republic
Port-au-Prince
Puerto Rico
Ottawa
Montreal
Toronto
New Brunswick
Nova Scotia
Prince Edward Island
Vermont
New Hampshire
Massachusetts
Rhode Island
Connecticut
New Jersey
Delaware
Maryland
District of Columbia
American biogas Council
www.americanbiogascouncil.org/biogas_maps.org

Methane as a source of inexpensive energy

Methane as a source of H2 (reducing potential)

Methane as an indirect feedstock (for example, via syn gas)

Methane as a direct biological feedstock

"Those who cannot remember the past are condemned to repeat it."

THE ICI SINGLE CELL PROTEIN PROCESS

P. J. Senior *
ICI Agricultural Division, Research & Development Department,
P.O. Box 1, Billingham, Cleveland, TS23 1LD

and

J. Windass
ICI Corporate Research Laboratory, The Heath, Runcorn, Cheshire

Biotechnology Letters, May 1980, Volume 2, Issue 5, pp 205-210

From Senior and Windass article

Methane was cheap—North Sea

Limited methane solubility in water (so energy needed for mass transfer)

Yield of biomass from methane was poor

Massive oxygen requirements (more energy for mass transfer)

Massive cooling loads

Large capital costs and needs to protect against explosion

The key initial enzyme, methane mono-oxygenase, consumes reducing equivalents that could otherwise be used for energy and biosynthesis

Theoretical potential

$CH_4 + ½\ O2 \text{ ---> } CH_3OH$

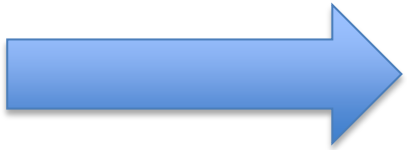
But in biology, methane conversion is catalyzed by methane monoxygenase (MMO)

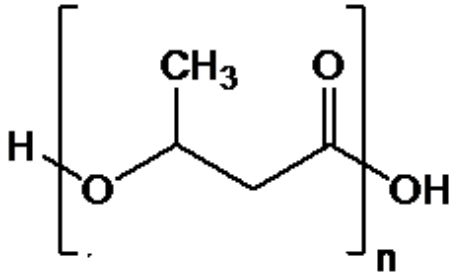
$CH_4 + O_2 + 2[H] \text{ ---> } CH_3OH + H_2O$

Need an external source of reducing potential

A brief "case study" of a bioproduct from 2 feedstocks

$C_6H_{12}O_6$ (glucose)





CH_4

(PHB)

"$C_4H_6O_2$"

PHB from glucose

$2\ C_6H_{12}O_6 + 6\ [H] \rightarrow 3\ C_4H_6O_2 + 6\ H_2O$

Get [H] from glucose

$C_6H_{12}O_6 + 6\ H_2O \rightarrow 6\ CO_2 + 24\ [H]$

Chemistry 101 balancing of equations:

$9\ C_6H_{12}O_6 \rightarrow 12\ C_4H_6O_2 + 6CO_2 + 18\ H_20$

Y = 0.64 pound product per pound feedstock

For glucose at $0.20/lb,

$0.31/lb for PBH (based on feedstock only)

Methane as sole feedstock

$4\ CH_4 \rightarrow C_4H_6O_2 + 14\ [H]$

Need to use excess [H]

$O_2 + 4\ [H] \rightarrow 2\ H_2O$

Chemistry 101 balancing of equations

$4\ CH_4 + 7/2\ O_2 \rightarrow C_4H_6O_2 + 5\ H_20$

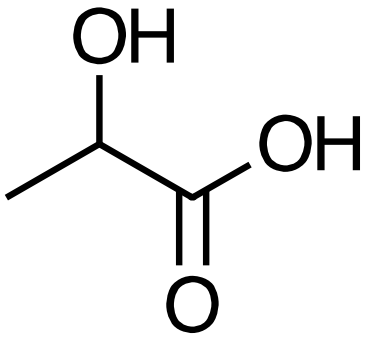
Y = 1.34 pounds of product per pound of feedstock!

CH_4 at $4 mmBTU is approximately $0.10/pound, so

$0.075/pound PHB (based on feedstock only)

(recall was $0.31/pound for glucose)

A quick look at lactic acid



From glucose

$C_6H_{12}O_6$ ---> 2 $C_3H_6O_3$

Y = 1.0 pounds of produce per pound feedstock

From methane

3 CH_4 + 3 H_2O ---> $C_3H_6O_3$ + 12 [H]

3 O_2 + 12 [H] ---> 6 H_2O

==========

3 CH_4 + 3 O_2 ---> $C_3H_6O_3$ + 3H_2O

Y = 1.875 pounds of product per pound of feedstock!

$0.053/pound based on feedstock!


Thank you
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Glucose, with methane as a source of [H]

$2\ C_6H_{12}O_6 + 6\ [H] \rightarrow 3\ C_4H_6O_2 + 6\ H_2O$

Methane as source of [H]

$CH_4 + 2\ H_2O \rightarrow CO_2 + 8\ [H]$

Chemistry 101 balancing of equations:

$2\ C_6H_{12}O_6 + 0.75\ CH_4 \rightarrow 3\ C_4H_6O_2 + 0.75\ CO_2 + 4.5\ H_2O$

Y = 0.72 pounds of product per pound of glucose feedstock

So need less sugar, at the expense of methane.