

Methane as a Feedstock for Bio-based Processes

An Industrial and Venture Perspective

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ARPA-E Biological Technologies for
Methane-to-Liquid Fuels Workshop
December 5, 2012
Washington, DC



**“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**

“Nature’s first green is gold”

from: Nothing Gold Can Stay, Robert Frost

Started November 23, 2011

\$355 million, early-stage investment company, backed by Warburg Pincus

Focused on the carbon value-chain

- Renewable carbon technology

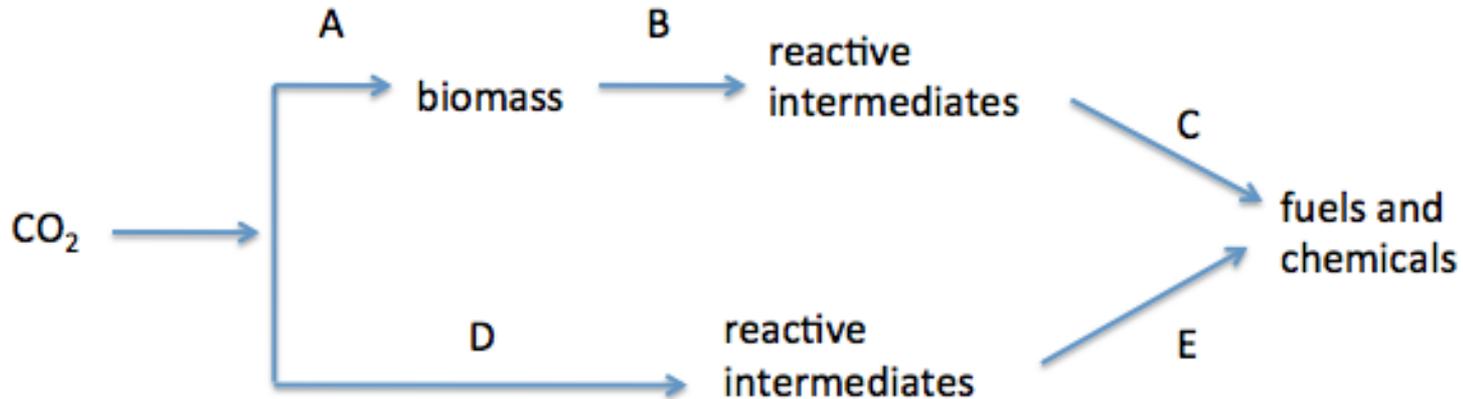
- Environmental/cleantech related to fossil carbon

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

Ability to do large follow-on investments for capital intensive deals

Carbon Value Chain

The Carbon Dioxide and Biomass Value Chain

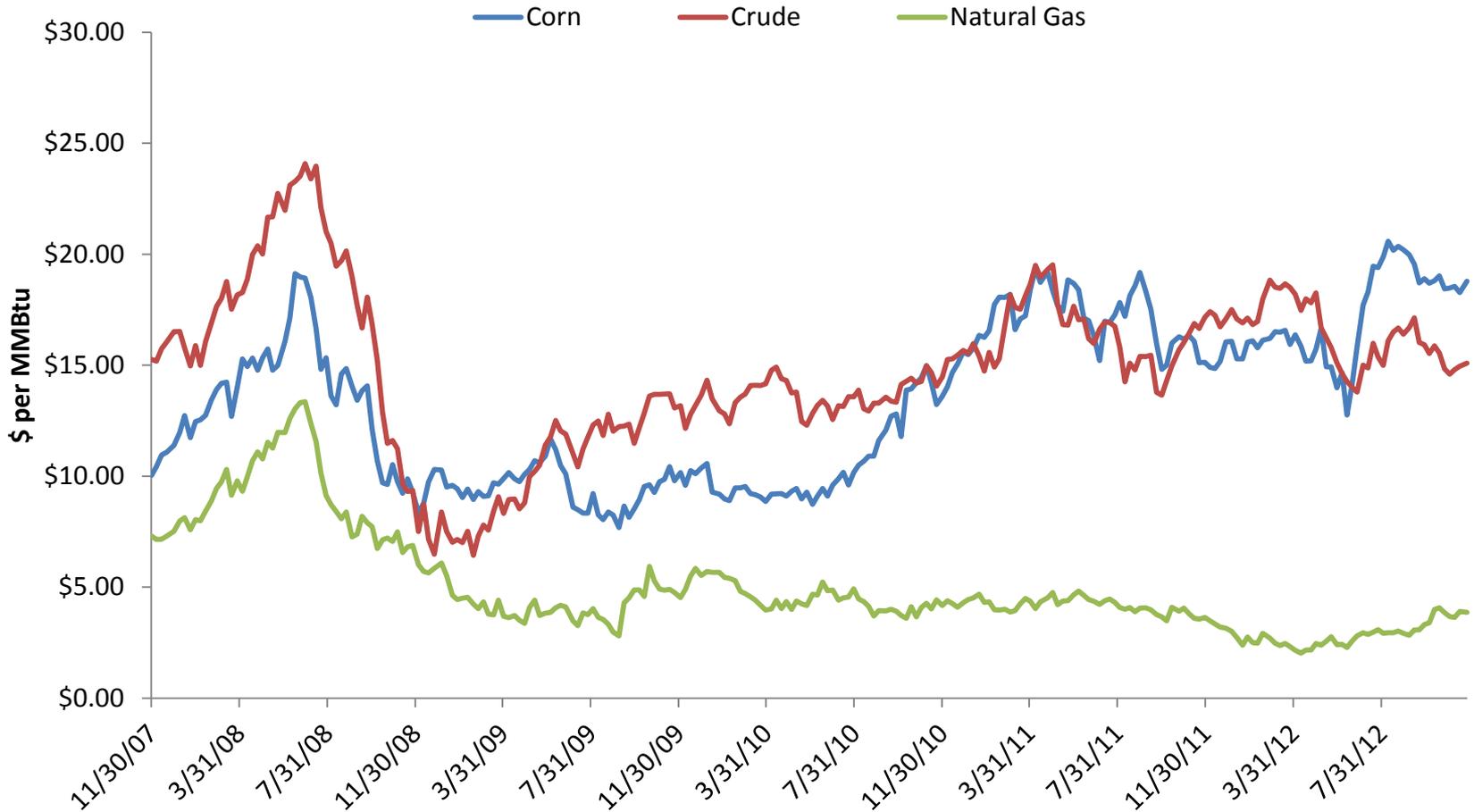


The Green-Black Value Chain



Application of green technologies to conventional energy value chain

Relative Cost Advantage of Methane

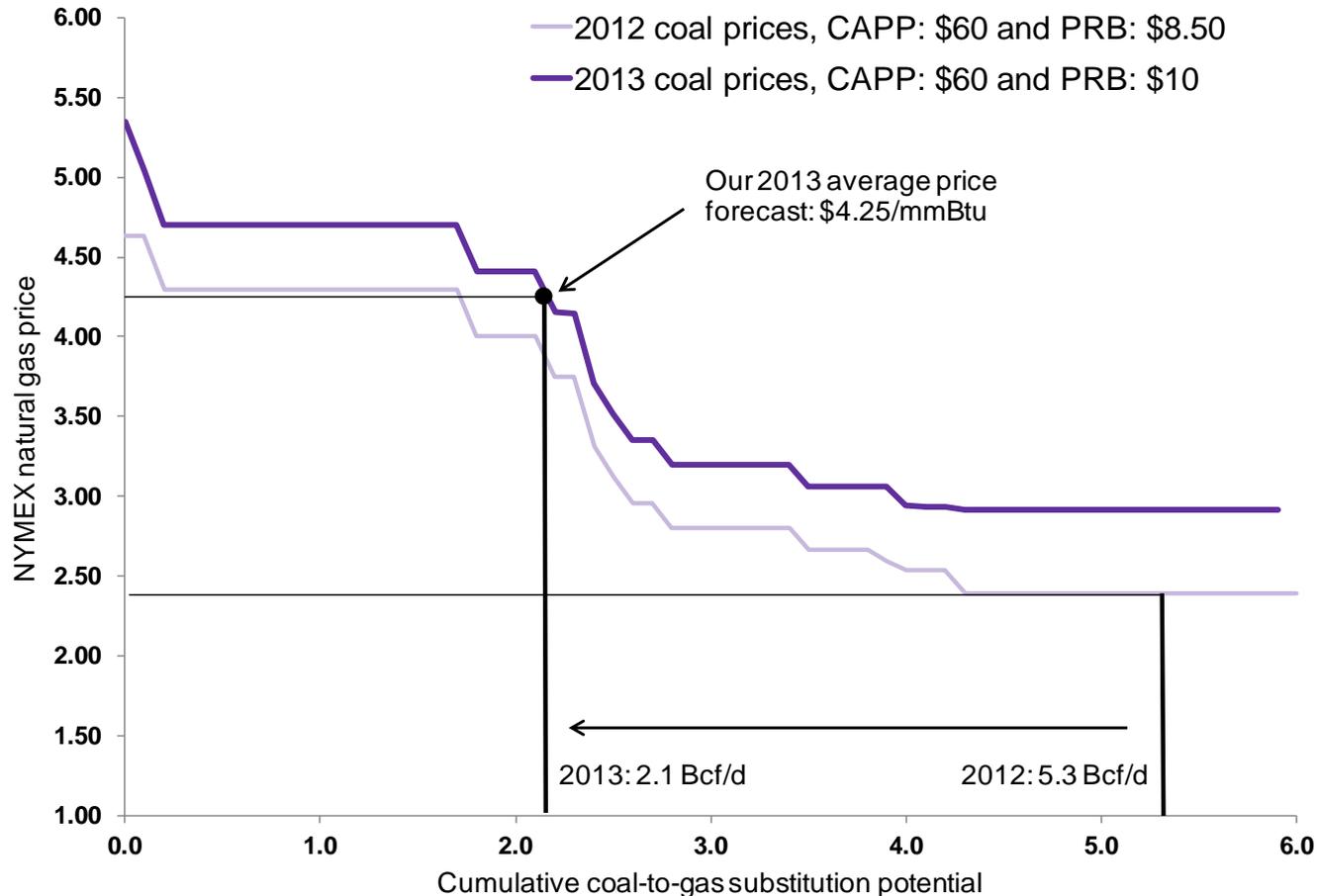


Source: CRB

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

Normal winter weather and stable production mean less need for switching in 2013, allowing prices to recover

Required gas price for a given amount of price-induced switching. Vertical axis in \$/mmBtu; horizontal axis in Bcf/d



New York Times, December 3, 2012

South African Company to Build U.S. Plant to Convert Gas to Liquid Fuels

By [CLIFFORD KRAUSS](#)

WESTLAKE, La. — In an ambitious bet that the **glut of cheap natural gas** in the United States will last for many years, a South African energy company announced on Monday that it would build America's first commercial plant to convert natural gas to diesel and other liquid fuels.

Sasol has designed its new Louisiana plant to produce 96,000 barrels of fuel a day using its "gas to liquids," or G.T.L., technology.

A boom in shale drilling has reduced the price of natural gas in the United States in the last four years by more than two-thirds, encouraging many energy and chemical companies to build and expand manufacturing plants around the Gulf of Mexico to produce a variety of petrochemicals.

Shell's Pearl Gas-to-Liquids Plant, Qatar, > \$18 billion



"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

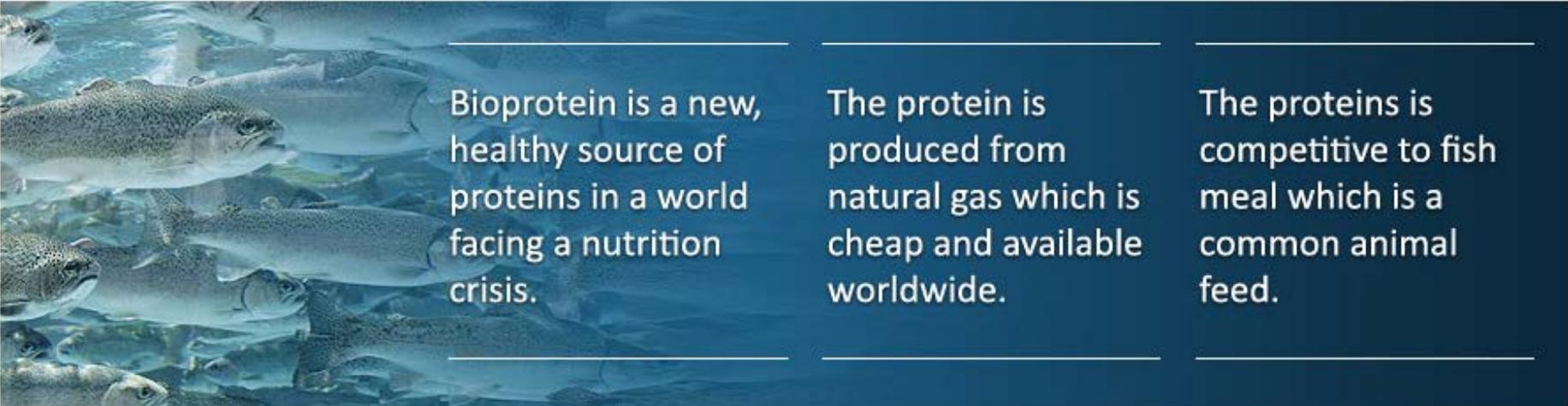
BioProtein, Norway



BioProtein AS

Bioprotein - a healthy protein source

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Bioprotein is a new, healthy source of proteins in a world facing a nutrition crisis.

The protein is produced from natural gas which is cheap and available worldwide.

The proteins is competitive to fish meal which is a common animal feed.

A bit more “history”

Direct biological use of methane

ICI single cell protein efforts (switched to methanol)

BioProtein, Norway

DuPont, carotenoid effort

Several efforts on polyhydroxyalkanoates

Indirect use of methane (source of carbon/hydrogen)

Syngas fermentation (Coscata, Ineos Bio, others)

Hybrid microbial-chemical routes (Zeachem)

“The best way to predict the future is to invent it.”

Cost per Raw Megabase of DNA Sequence



Some opportunities and directions?

Cloning and expression of MMO's in alternative hosts

Development of robust industrial host organisms

Industrialization of anaerobic methane oxidizers/anaerobic pathways

Integrate sugar and methane use?

Discovery of new enzymatic activities and pathways

(go to the chemical methane utilization literature—there are likely enzymes or pathways for many of the reactions; water-gas-shift is an example)

Design and utilization of microbial consortia; spatially complex systems

Novel bioreactor design for mass and heat transfer

Cell-free systems?

New Technology from a VC Perspective

A strong team/founder

A group that can attract other great people and can adapt quickly

Potential for disruptive economics

~30% better than best available commercial technology
(important to understand the competitive landscape)

Intellectual property

Once the rest of the world hears your idea, how to keep them from “eating your lunch”

Business model

How does this idea/technology eventually make money?



Thank you

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