

# Algae - What will it take?

Vinod Khosla  
Khosla Ventures  
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# agenda

- › The Innovation Handbook
- › Key Criteria
- › Black Swans

# not your niche markets anymore!

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## Main Tech

### The Markets You Think Of

- > Engines (\$200B)
- > Lighting (\$80B - US)
- > Appliances (\$10'sB+)
- > Batteries (\$50B+)
- > Gasoline (\$500B+)
- > Diesel (\$500B+)
- > Jet Fuel (\$100B+)
- > Cement (\$100B+)
- > Water (\$500B+)
- > Glass (\$40B)
- > Home Building (!!!)
- > BioPlastics (\$10'sB+)
- > Power Generation (\$250B – US)
- > Solar Thermal
- > EGS
- > Clean Coal
- > New Nukes

... **”relevant cost”**  
... **”relevant scale”**  
... **”relevant adoption”**

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# ...the chindia test

only scalable if competitive unsubsidized

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“1990: Chindia  $\approx$  13% of CO<sub>2</sub> emissions  
2005: Chindia  $\approx$  23% of CO<sub>2</sub> emissions  
2030: Chindia  $\approx$  34% of CO<sub>2</sub> emissions”

EIA

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# ...the scaling model

brute force or exponential, distributed..

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# ...the adoption risk

financial, consumer acceptance, market entry

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... **”relevant scale”** solutions for

... **oil**

... coal

... materials

... efficiency

# Khosla Ventures' rules of investing

Attack manageable but **material** problems

Technology that achieves **unsubsidized** competitiveness

Technology that **scales** - if it isn't cheaper it doesn't scale

Manageable startup costs & **short innovation** cycles

**Declining cost** with scale - trajectory matters

...technology expands the “Art of the Possible”

to predict the future, **invent it!**

...today's “unimaginable” is tomorrow's  
“conventional wisdom”

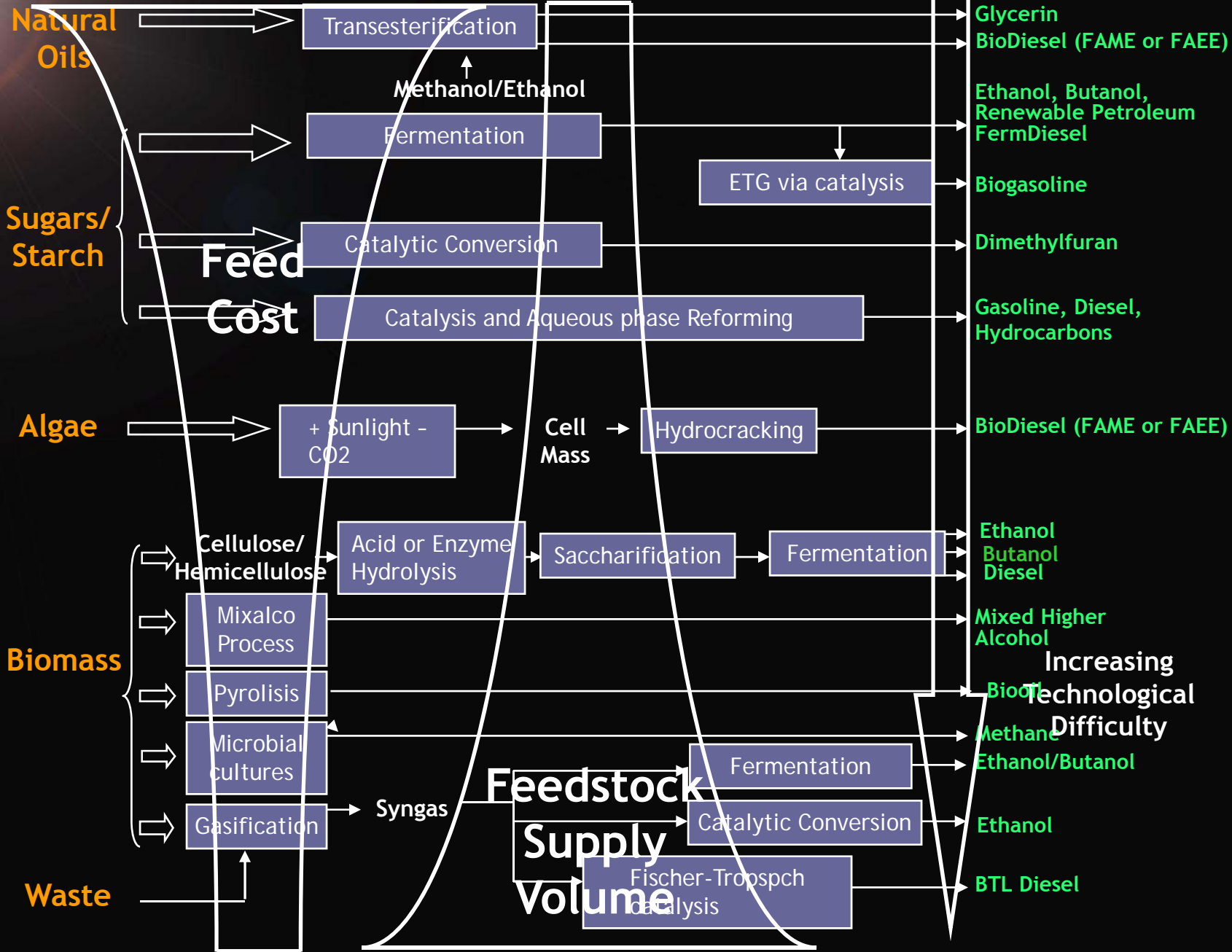
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- › The Innovation Handbook
- › Key Criteria
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# key criteria

- › Trajectory: "What is" or "What Can Be"
  - › Scalability Trajectory
  - › Cost Trajectory

# trajectory: scalability



# trajectory: scalability

Gallons oil / acre / year



# trajectory: scalability

Gallons oil / acre / year  
~440

**Warning:  
Extrapolated  
from small  
sample**



Year round average  
7g/m<sup>2</sup>/day

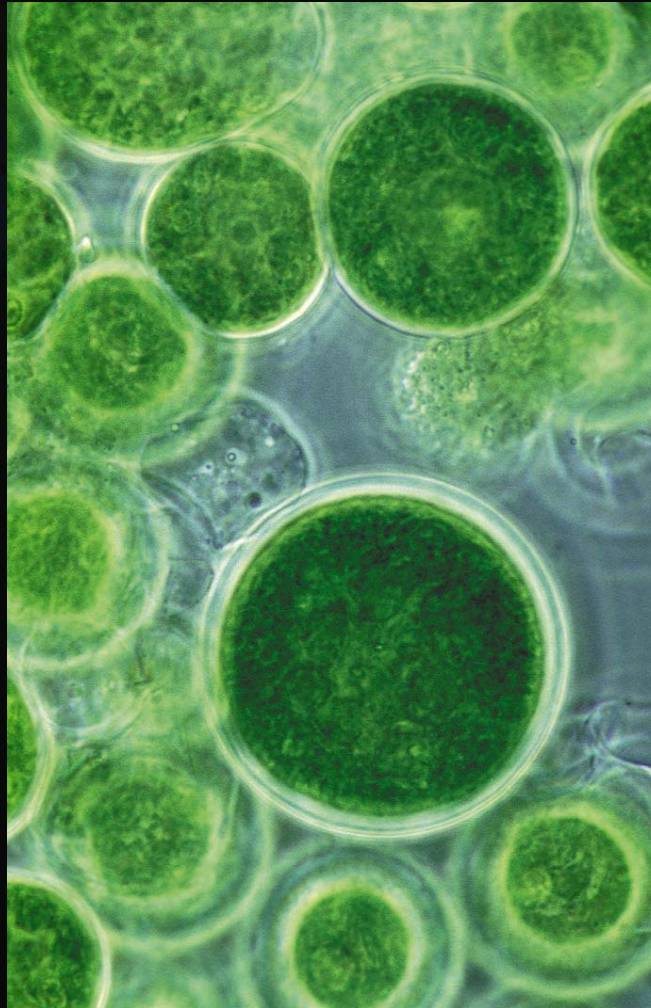
Ulva



# trajectory: scalability

Gallons oil / acre / year  
~1600

**Warning:  
Extrapolated  
from small  
sample**



Year round average  
16 g/m<sup>2</sup>/day

Confidential microalgae

# trajectory: scalability

Gallons oil / acre / year  
~3100

**Warning:  
Extrapolated  
from small  
sample**



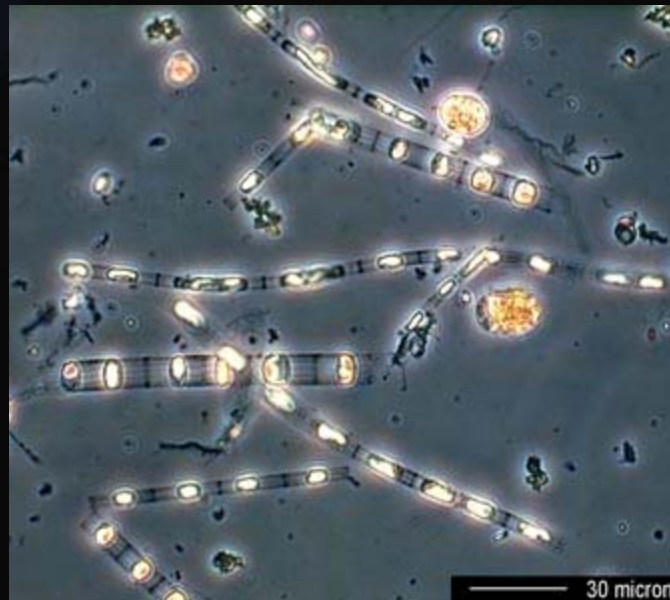
Year round average  
30 g/m<sup>2</sup>/day

microalgae

# trajectory: scalability

Theoretical  
gallons oil / acre / year  
~6500

**Warning:  
Extrapolated  
from small  
sample**



240 day average  
61 g/m<sup>2</sup>/day

Skeletonema costatum

# trajectory: scalability

## Theoretical MAXIMUM Gallons oil / acre / year

7.2 GJ	US Southwest solar energy
x 90%	Reaches algae
x 45%	Photosynthetic active radiation
x 90%	Photons absorbed by PS pigments
x 22%	Photosynthetic efficiency
x 25%	Post light saturation and photoinhibition
x 85%	Post respiration
	@ 20 GJ/mt biomass, 60 mt/ha-yr, 30% oil
~	<b>2,000-6,000* gallons oil / acre / year</b>

\* "Maybe 2-3x (2,000 gallons oil / acre / year) with genetically improved algae"

J Benemann

# trajectory: **cellulosic scalability**

## **Miscanthus**

17 tons / acre

## Ethanol

1500-1800 gallons / acre / year

## Oil

1980-2500 gallons / acre / year



# trajectory: **cellulosic scalability**



## **Sorghum**

25 tons / acre

## Ethanol

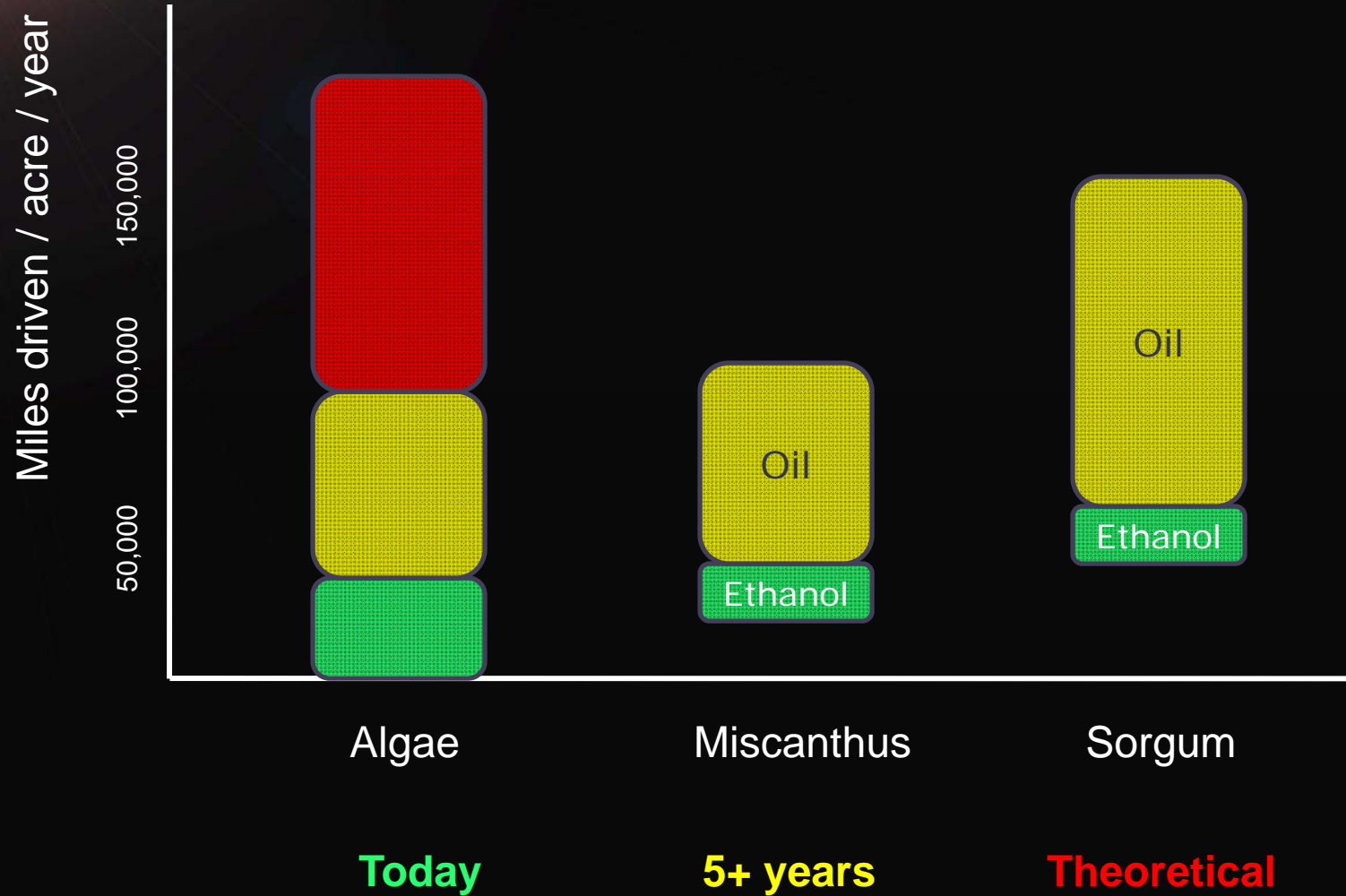
2250-2750 gallons / acre / year

## Oil

3000-3750 gallons / acre / year

(Prof. Holtzapfle- Texas A&M)

# trajectory: yields



# “biocrude” replaces crude



Crude oil

Refinery

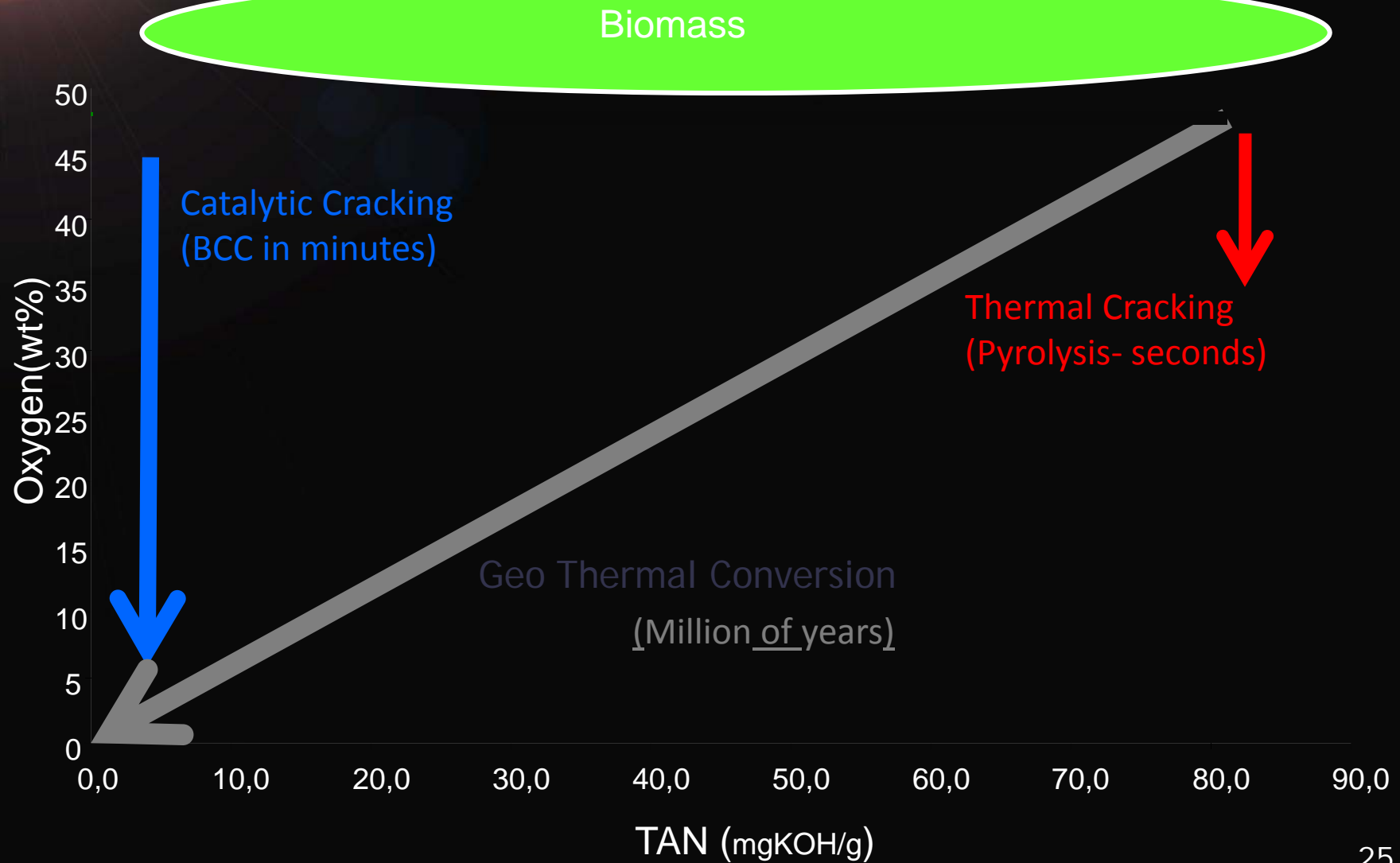


Biocrude





# Kior: Millions of years → Minutes!



# key criteria

- › Trajectory: "What is" or "What Can Be"
  - › Scalability Trajectory
  - › Cost Trajectory

# trajectory: fertilizer costs

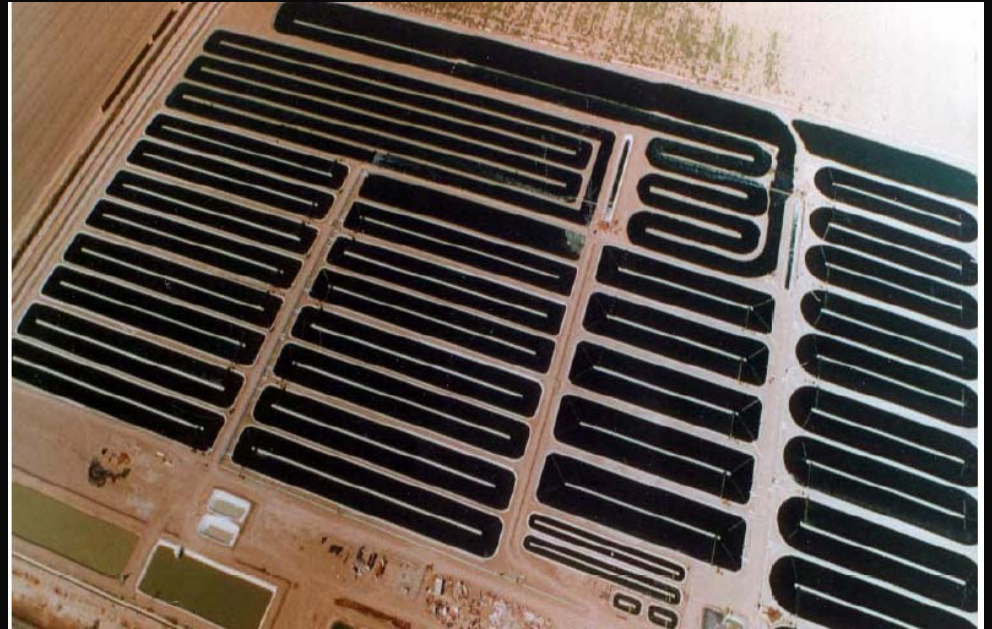


Vs.



## trajectory: **harvesting costs**

How to remove  
a ton of  
microscopic  
particles from  
many tons of  
wet media—  
daily?



# trajectory: **harvesting costs**



**Vs.**



x 100??

## trajectory: **containment cost**

How to contain  
thousands of  
tons of media—  
cheaply?



Source: Solix

# trajectory: **containment costs**



Vs.



# trajectory: **containment costs**



Vs.



Source: AlgaeLink



# trajectory: **containment costs**



**Vs.**



Source: Valcent

# trajectory: **containment costs**



Vs.



Source: Live fuels

# trajectory: **containment costs**



**Vs.**



Source: Algenol

# trajectory: **containment costs**



**Vs.**



# trajectory: energy costs

How to move,  
mix, or add light  
to thousands of  
gallons of  
media—cheaply?



Source: Seambiotic

# trajectory: energy costs



Vs.



Pumps & Paddles

# trajectory: energy costs



Vs.



Light

Source: Helix BioReactor (Origin Oil)

trajectory: **other cost reduction strategies**

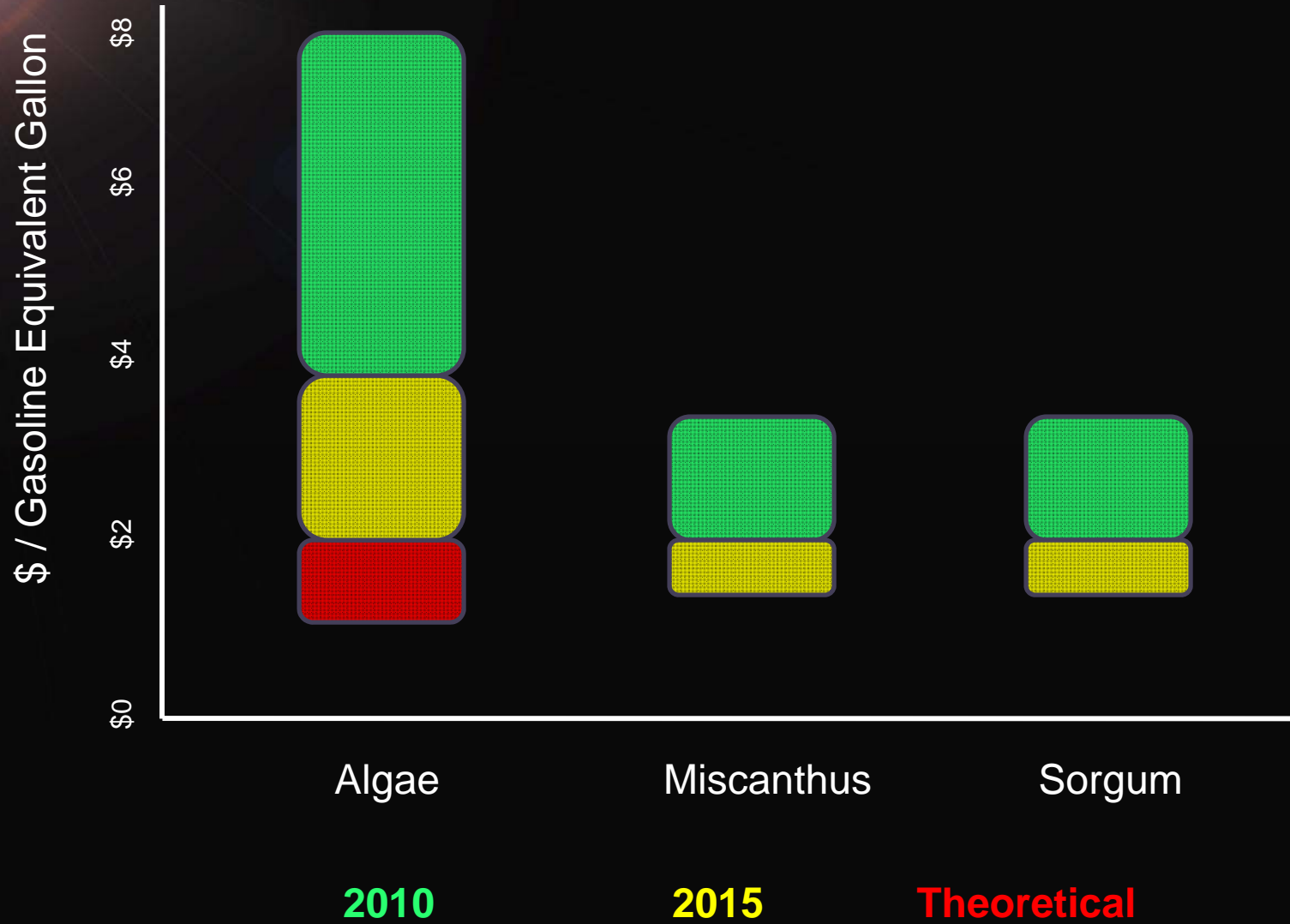
**Co-products**

*like fish or animal feed*

**Fertilizer from human or  
industrial waste**



# trajectory: costs



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# “black swan” solutions ?

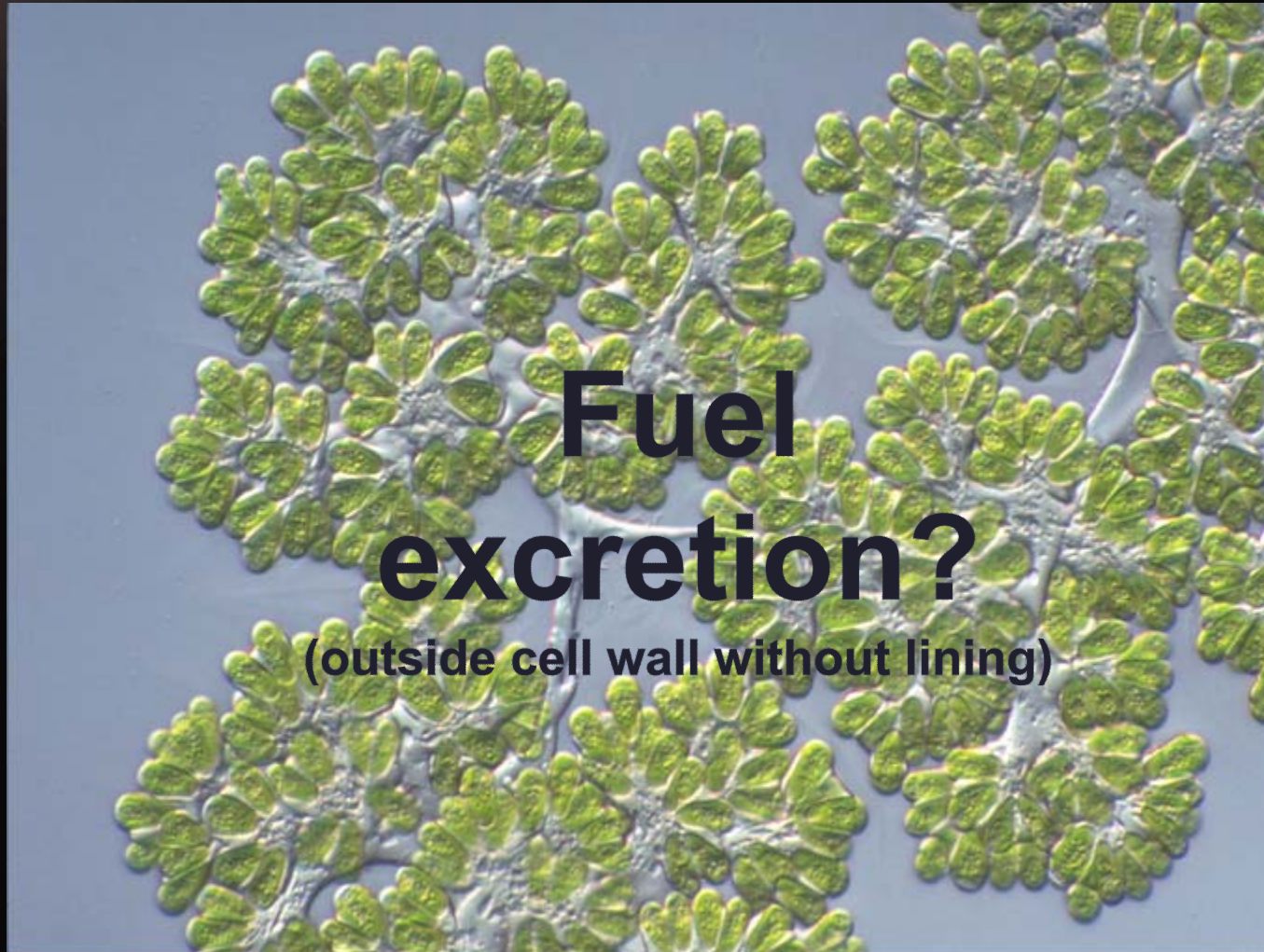
Black Swans events are:

- › Outliers: outside realm of traditional expectations
- › Material: make significant, game-changing impact

› Justifiable, not predicted, but justified on ex post basis  
**Technology shocks are classic “Black Swans”!**

Strategy: More “at bats”; “shots on goal,” and retrospective  
**“rarity, extreme impact,” and retrospective  
(though not prospective) predictability”**

# Black swan algae idea



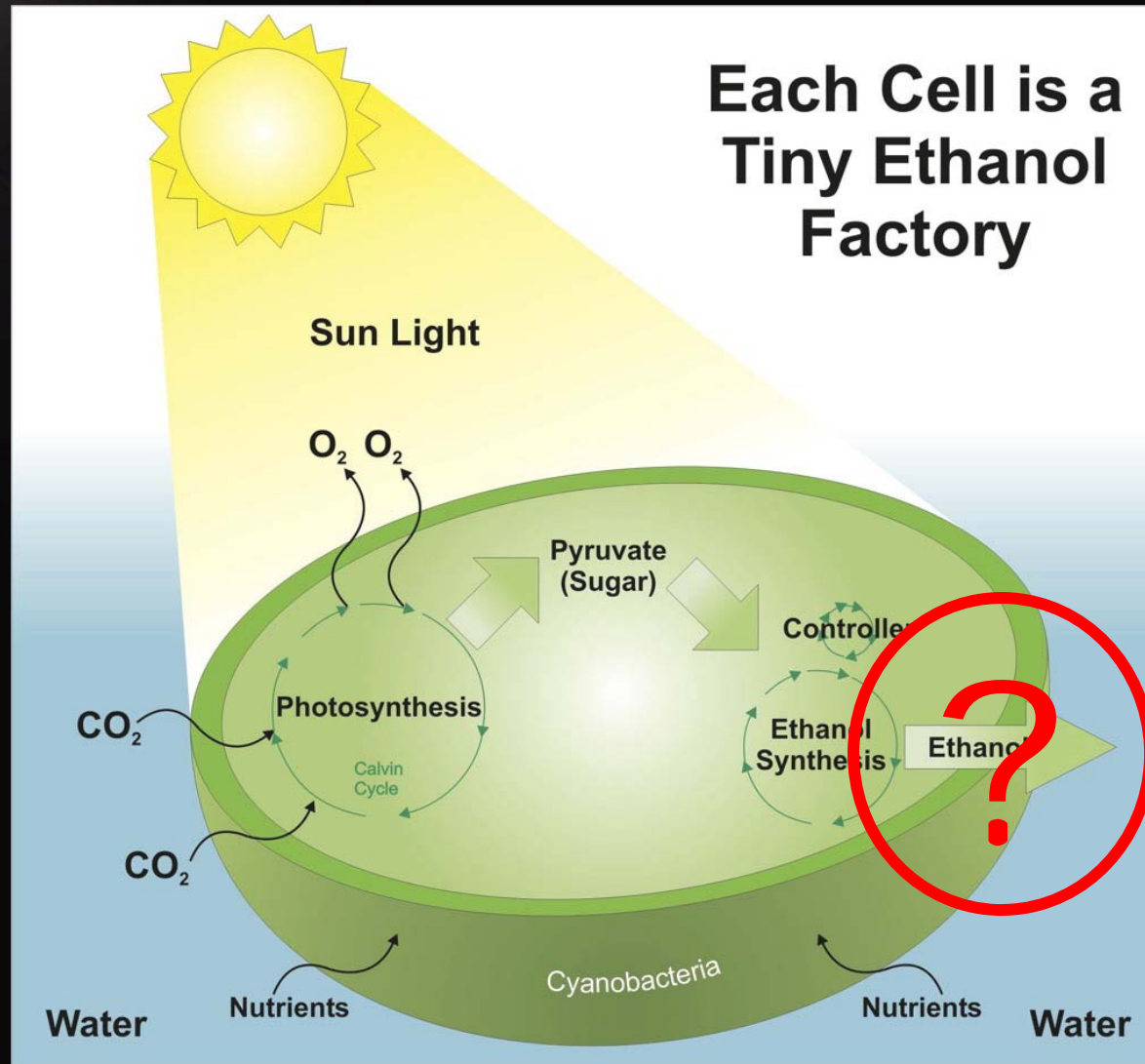
**Fuel  
excretion?**

(outside cell wall without lining)

NIES-836 *Botryococcus braunii*

10  $\mu$ m

# Black Swan? Algenol



# Black Swan? Sapphire Energy

A microscopic image showing several large, spherical green algae cells with a textured surface, surrounded by many smaller, similar cells. The background is a light blue color.

sunlight + CO<sub>2</sub> + sapphire = renewable gasoline

# Black swan algae idea



The New York Times Magazine

JANUARY 4, 2009 / \$10 US

# Watching the World Melt Away

The future as seen by a lonely scientist at the end of the earth. By Darcy Frey

Beverly Sills's Frustrating Last Act, by Frank Bruni · America's Go-To Wardrobe, by Peter Maass

...or get to **work**

[vk@khoslaventures.com](mailto:vk@khoslaventures.com)  
[khoslaventures.com/resources.html](http://khoslaventures.com/resources.html)