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A new paradigm for biofuels, biofeedstocks, and climate change mitigation and adaptation

Low-Carbon Fossil Power Generation

The Algae-Oxyfuel Synergy

EUCI Webinar - November 12 ,2009

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A2BE Carbon Capture LLC
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Correction on Slide 15

Agenda

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- Orientation to the Algal Industry
- Sustainability and Lifecycle Metrics
- Advantages: Conventional Oxyfuel Combustion
- Disadvantages: Conventional Oxyfuel Combustion
- Algae Synergy: Roller-Film Algae Cultivation Plus Oxyfuel
- Case: Coal-Electric Retrofit to Oxyfuel with CC&R
- Siting and Regulatory
- Crystal Ball Predictions
- Finding More Information

Orientation to the Algal Industry

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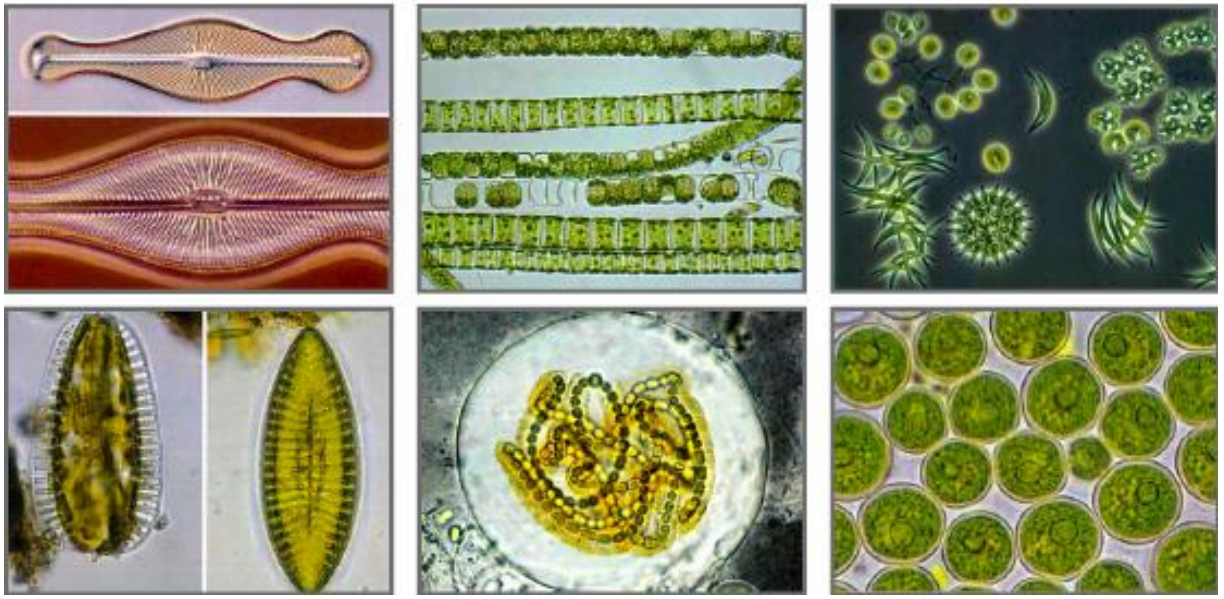
Nature's answer for fuel, food and climate change

- Masters of photosynthesis: Solar Powered Chemical Production
- Food and Fuel grown on non-arable land w/potentially low water needs
- CO_2 Emissions Recycled into Products
- Alga is a single cell, Algae is the plural of alga, Algal is an adjective

Micro-algae like these require microscopes

Macro-algae includes seaweed



Courtesy Dr. Milton Sommerfeld, ASU

Industrial vs. Biological Respiration

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CO2 Expelling Examples (Energy Released via Oxidation)

- Humans oxidize food
- Automobiles oxidize fuel
- Bacteria, Bugs & Yeast
- Coal & Gas Fired Power plants
- Fertilizer and Chemical plants

Industrial Intensity at Present

CO2 Consuming Examples (Energy Stored & Oxygen Released)

- Domestic Crops release oxygen
- Ocean Plankton
- Forests and Grasslands
- Carbon Capture & Recycle (**CC&R**) algal farms

Industrial Intensity Desired

CC&R: Allows Solar Power to be Stored in High Value Chemicals

How to Productize CO2 Emissions

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Sun Restores Value to CO2 by Recycling back to Products

Concentrated CO2
from Stationary Sources

- Coal to Liquids
- Power Plants
- CO2 Pipelines
- Cement Plants
- Fertilizer Plants
- Fuel Refineries

Solar Driven Photosynthesis

Industrial Photo-bioreactor Farm

Bio-Product Outputs
from Algal Conversion

- Liquid Biofuels
- BTUs & Methane
- Feed Protein
- Chem. Precursors
- Industrial Oxygen
  –some processes-
- Soil Amendments

Commodities & Chemicals Derived from Algae

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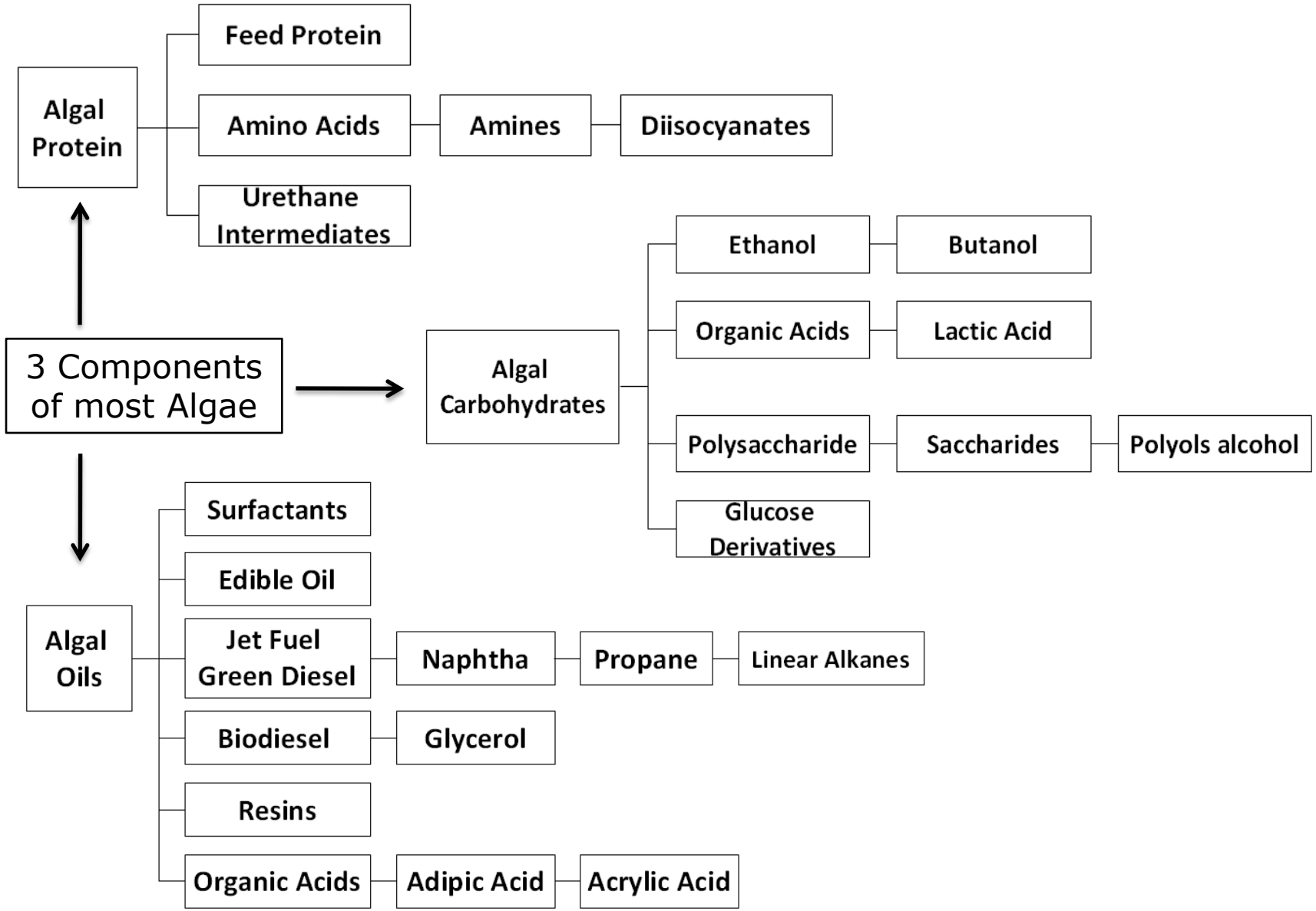

Sectors and Interfaces of the Algal Industry

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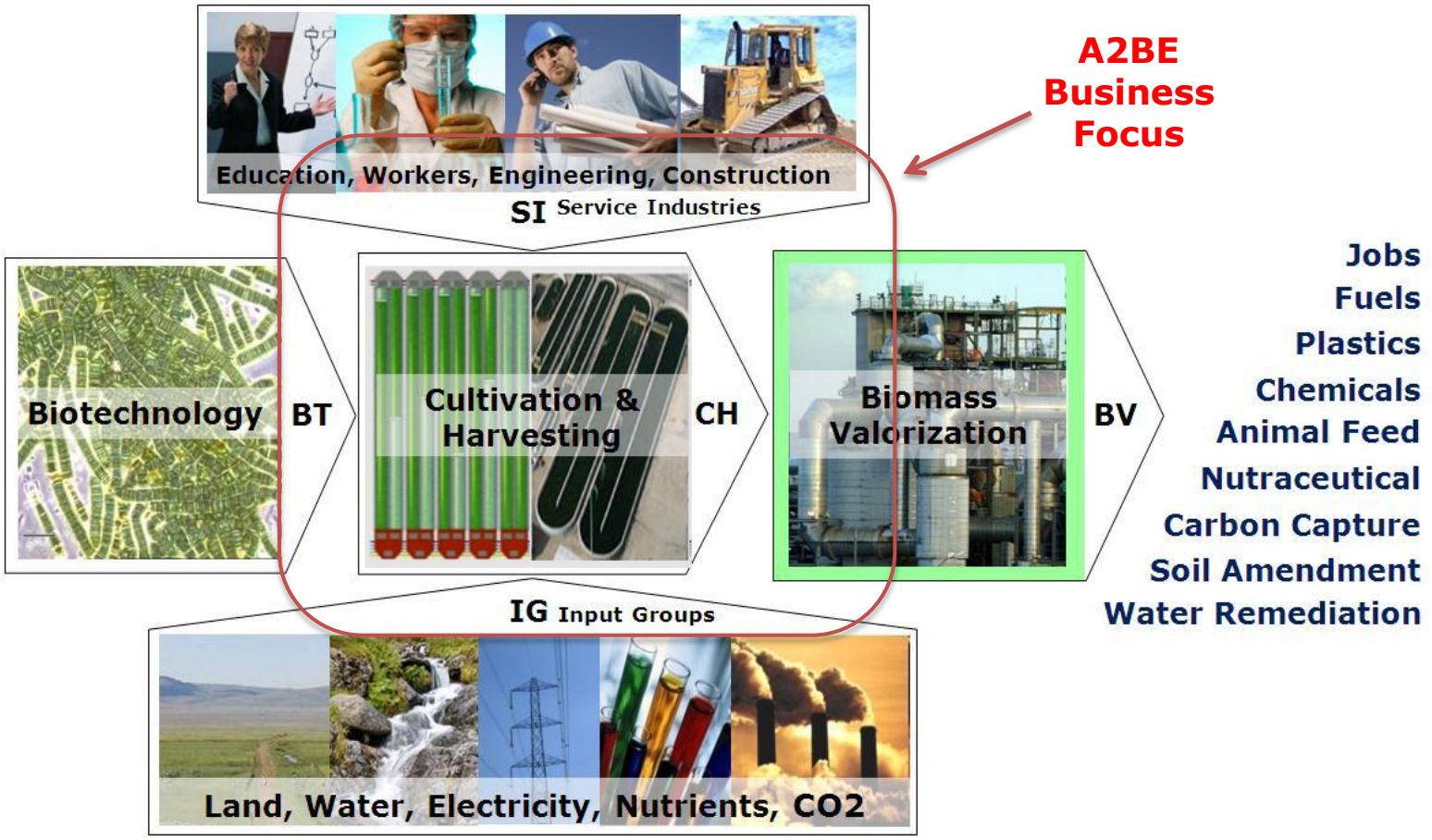

Present State of Development

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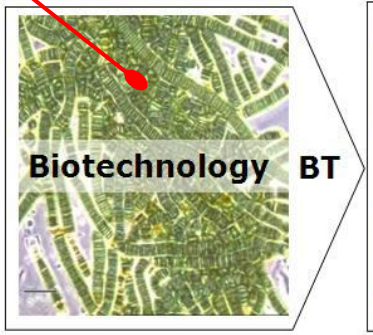
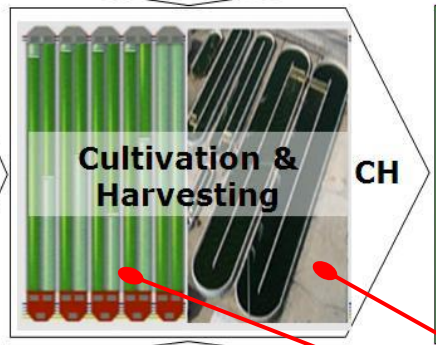
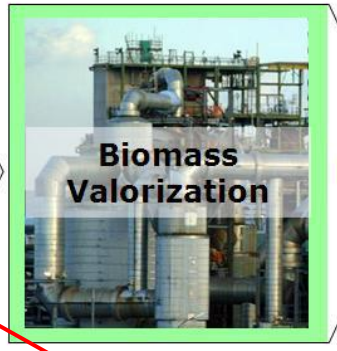
Long-lead Workforce Development

Mostly Proven in Lab

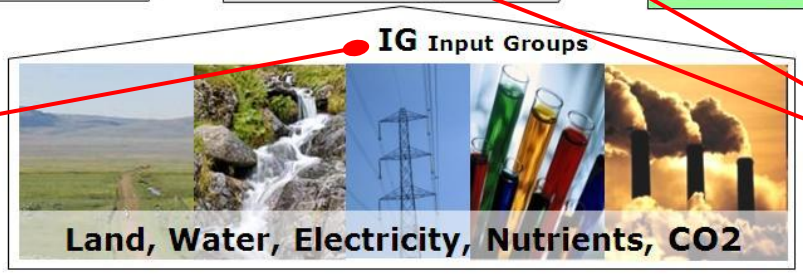






Mostly Proven in Lab

Jobs
Fuels
Plastics
Chemicals
Animal Feed
Nutraceutical
Carbon Capture
Soil Amendment
Water Remediation



Complex Engineering and Regulation but Doable

Cultivation is Chokepoint of Regulation, Reliability, Sustainability & Productivity

Different Approaches to Cultivation of Algae

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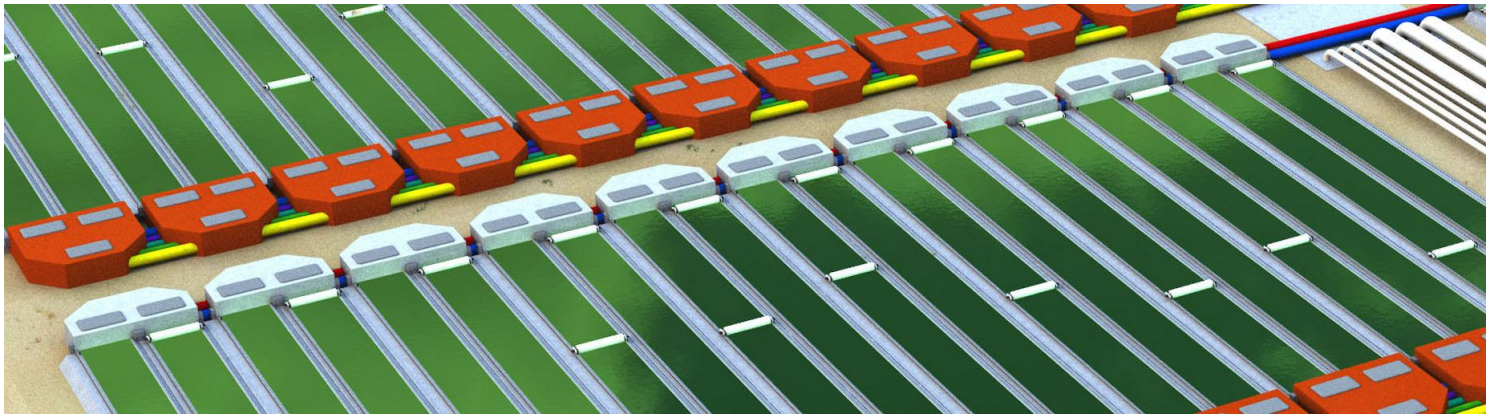
"Open Raceway Ponds"

- Traditional technology, yet minimal usage
- Req. High humidity, Plentiful fresh water, Easy climate
- Lower in cost, Low gas control & product quality

"Closed Photobioreactors"

- Still in development, no commercial usage
- Ok for Low humidity, Scarce fresh water, Hard climate
- Higher in cost, High gas control & product quality



Performance and Sustainability

Metrics for Algae

- Typical Working Values for Scenario Computation

Typical Algal Productivity & CO2 Uptake

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Future A2BE Closed System Est. Biomass Productivity:
Average photosynthetic productivity: 55 grams-dw/m2-day

- Typically only75% of farm infrastructure can be photosynthetic
Farm Infrastructure Biomass Productivity: 60 Mt-dw/acre-year

- Biomass is approximately 50% Carbon. CO2 is 12/44ths = 27% carbon
Yearly Farm Uptake of CO2: 110 Mt CO2/acre-year

- A reasonable expected "Fuel Fraction" of oil would be 30% of biomass
Oil Fuel Fraction per acre: 30% of 60 = 18 Mt/a = 5000 gal/acre

Future Open System Est. Biomass Productivity: ½ of A2BE Sys.
Average photosynthetic productivity: 27.5 grams-dw/m2-day

- Assume same 75% Infrastructure Photosynthetic fill factor
Farm Infrastructure Biomass Productivity: 30 Mt-dw/acre-year

- Biomass still approximately 50% Carbon. CO2 is 27% carbon
Yearly Farm Uptake of CO2: 55 Mt CO2/acre-year

- A reasonable expected "Fuel Fraction" of oil is still 30% of biomass
Oil Fuel Fraction per acre: 30% of 30 = 9 Mt/a = 2500 gal/acre

Fresh Water Use with A2BE's Closed System

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Future A2BE Closed System Est. Fresh Water Use:
4 inches per year over area of photosynthesis.

- Roughly 75% of A2BE farm infrastructure is photosynthetic so
Consumption = 3 inches/year over algae farm infrastructure

- **Closed system has no incidental evaporation of water percolation**
- **A2BE's switchable thermal barrier predominantly cools farm w/o water**
- **Some water's hydrogen chemically converted to biomass**
- **Some water evaporated during cleaning and process flushing**
- **Most water used for occasional nighttime cooling of insulated system**
- **Does not include precipitation water saved by inhibiting soil evaporation**

A2BE Water Consumption per Product Output

- At 3" water consumption per acre
Consumption = 82,000 Gallons/acre-year

- At 5000 gallons/acre plus 42 tons residual biomass production:
5 gallons water per 1 gallon oil and 5 Kg water per 1 Kg biomass

Evaporation is Core Issue for Open Systems

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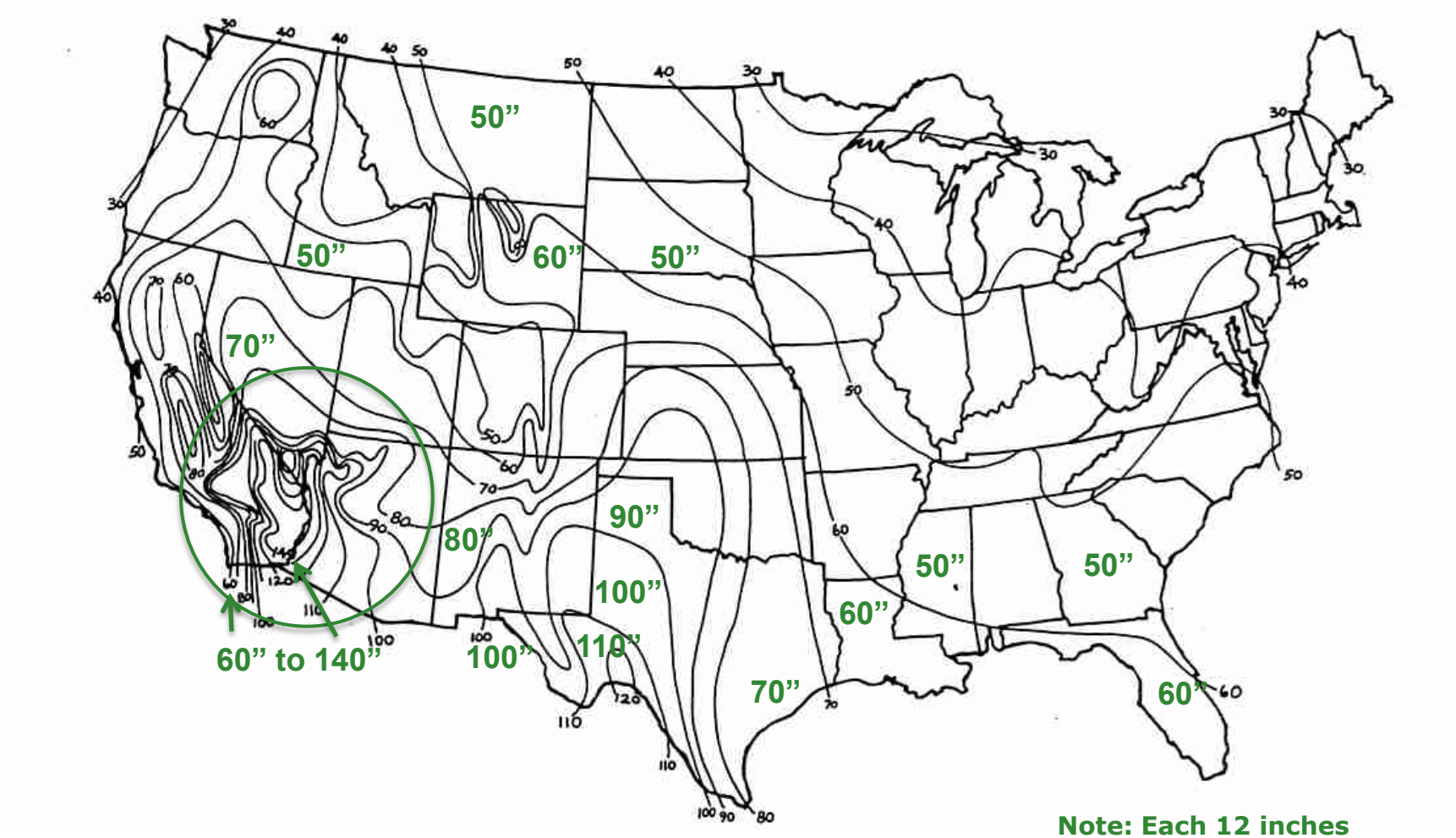
Pan Evaporation Map: Courtesy University of Arizona



Labels show the inches of fresh water that would evaporate from an open system per year

Note: Each 12 inches represents 1 acre foot: 330,000 gallons/full-acre

Fresh Water Use with Open Pond System

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Open Pond System Estimated Fresh Water Use:
Assume average of 60+ inches pan evaporation per year

- Roughly 75% of Open Pond infrastructure is exposed so
Evaporation = 45 inches/year min over algae farm acreage

- If we assume other water losses are comparatively small then:
- Open Pond fresh water consumption = primarily evaporation

Open Pond Fresh Water Consumption per Product Output

- At "modest" 45" net water evaporation per acre
Consumption = 1,230,000 Gallons/acre-year

- At 2500 gallons/acre plus 21 tons residual biomass production:
150 gallons water per 1 gal oil and 150 Kg water per 1 Kg biomass
The numbers in red "150" are a correction. The webinar incorrectly stated "500" for this value.

Using brackish or salt water in open ponds *does not help*

- What evaporates is fresh water, not salt water, and it must be replaced
- Diluting with huge amounts of brackish water may damage aquifers
- Requires periodic "blowdown" disposal of highly saline algae waste water
- Growing w/seawater inlet-outlet discharges algae waste products into sea

Energy Balance: A2BE Closed System

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Future A2BE Closed System Est. Energy Usage:

4 KW/acre continuous for cultivation system

2 KW/product-acre continuous for extraction, drying, productizing

- **Simplest product to analyze is dried whole algae for feed application**
- **New innovations in belt extraction and drying dramatically reduce power**
- **1 acre cultivation plus product creation uses 50,000 KWhr/acre-year**

Power into product: 0.85 KWhr/Kg dry algae feed

- A biomass energy value that Pimentel uses is 4.2 KWh/Kg biomass

A2BE energy balance = 5

- (5x more energy is stored as food than is consumed as electricity)

Energy Balance: Open Pond System

- **Not enough information available to calculate**
- **Replacing lost water using deep low-salt aquifers said to use a lot of power**

Other Considerations in Algal Sustainability

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- Efficient use and inter-plant recycling of nutrients
- Reliance on waste water sources for nutrients
- Embedded energy and CO2 footprint of farm inputs
- The life span of a farm infrastructure and CO2 footprint
- Portion of open system CO2 that enters atmosphere
- Hazardous biological emissions from open systems
- Hydrocarbon air emissions from open systems
- Air quality and animal pollution of open systems
- The carbon lifecycle effect of different algal products

…Sustainability is a complex topic

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Advantages:

Conventional Oxyfuel Combustion

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Engineering Requirements of the "Hot, Flat, and Crowded" Global Era

- More Electricity per Person, & More People
- Reduced Carbon Life Cycle Emissions
- Mixed Coal, Methane and Biomass fuel inputs
- Grid Integration with Transient Power Sources
- Cross-Industry Synergistic Business Alliances
- Export of Sustainable Low Carbon Technologies

OxyFuel Combustion: What is it?

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Oxyfuel burns fuel in nitrogen free environment such that flue gas is already chiefly CO2 without needing to remove nitrogen

- Air Separation Unit (ASU) provides 95 to 97.5% pure oxygen
- Some CO2 is recycled through combustion to prevent boiler melting
- Can be used with pulverized coal, methane, or biomass co-firing
- Oxygen Transport Membrane (OTM) combustion not covered here

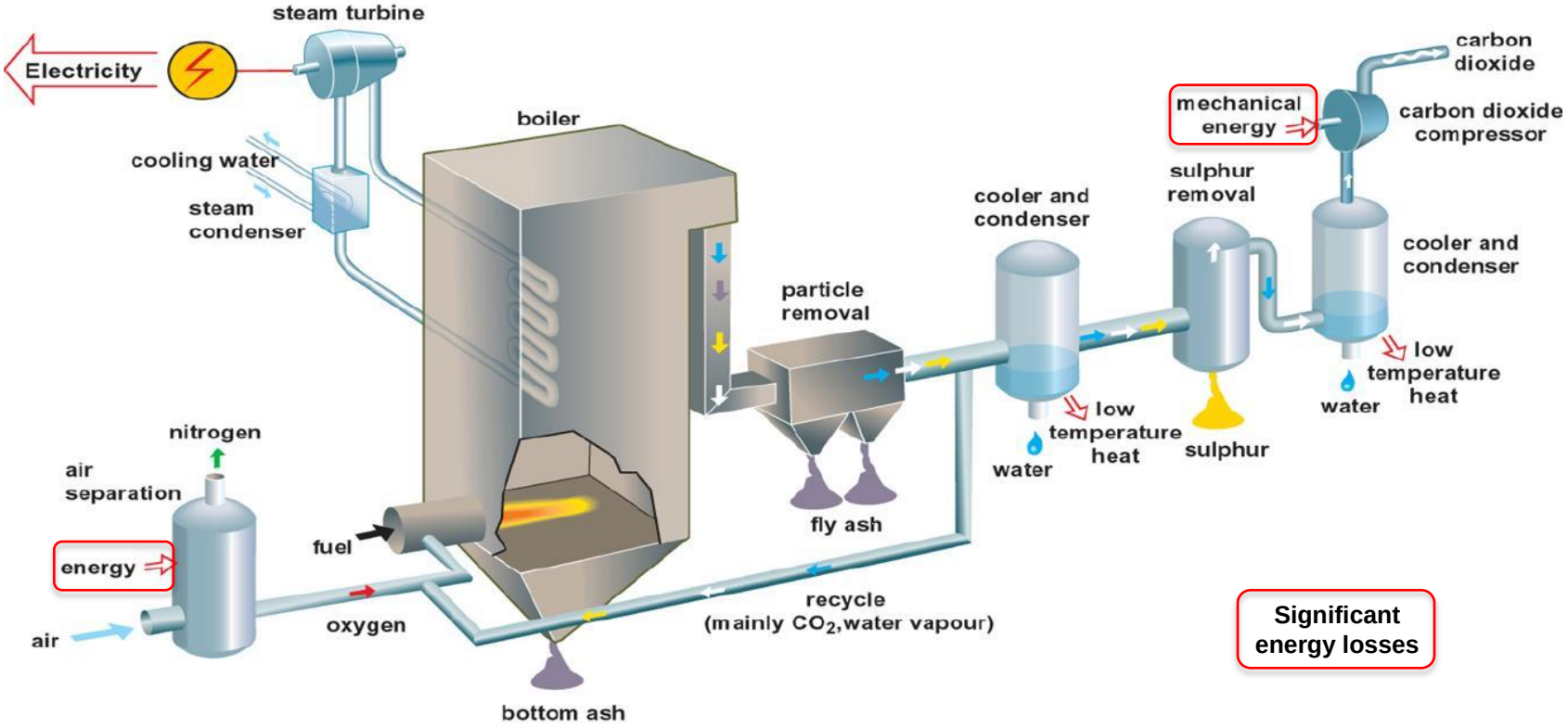

Figure courtesy of Vattenfall

OxyFuel Advantages

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Oxyfuel predominantly simplifies Carbon Capture - but also provides other important advantages

- Potentially[1] higher Carnot generation efficiency
- Potentially[2] increase plant generation capacity
- Potentially[3] lower generation of NOx
- Can often be retrofitted into older power plants
- NOx & SOx removal easier from smaller gas volume
- Enables future "topping cycles" to add efficiency

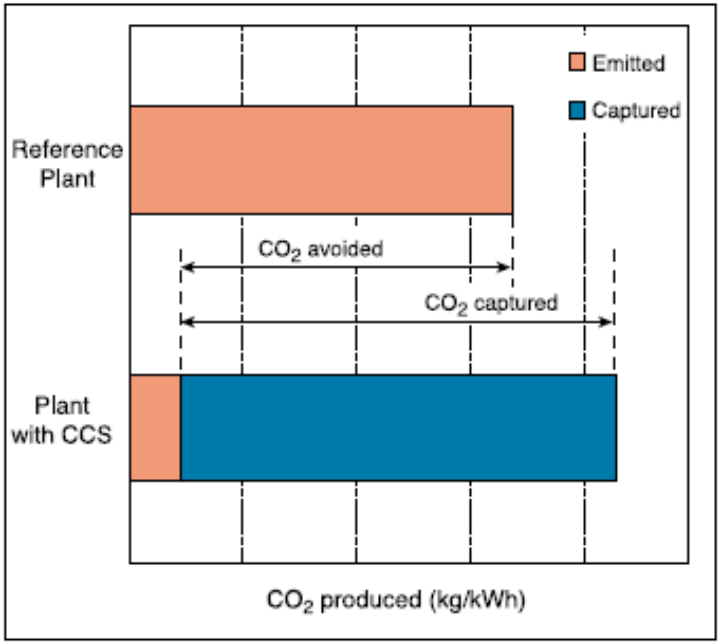
1. Limited by NOx and materials at high temperatures needed for high Carnot eff.
2. Capacity increase of 15% dominated by additional 23% of parasitic load
3. Nitrogen inherent in coal and biomass means NOx removal still needed

Disadvantages:

Conventional Oxyfuel Combustion

In practice efficiency and capacity advantages lost to oxygen generation and CO2 compression demands

- Modern Oxyfuel concepts lose 23% gross generated power due to oxygen generation and CO2 compression
- 23% more fuel is burned for each unit of power
- Net electricity production reduced 10-23% over pre-Oxyfuel



Currently <u>all</u> new plant designs need to burn more fuel and generate more CO2 in order to generate the additional power needed to sequester CO2

OxyFuel Waste through CCS Sequestration

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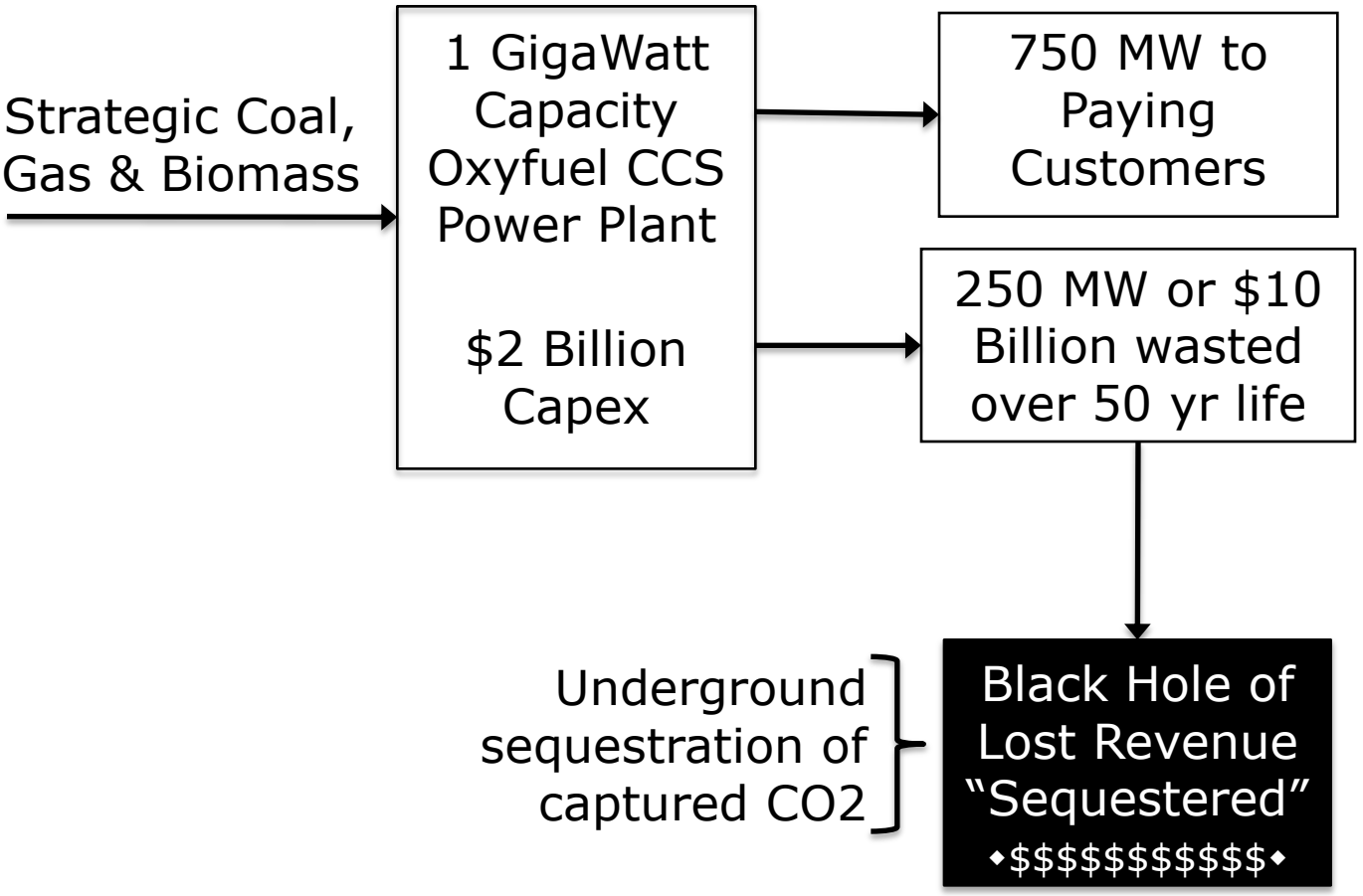
Pumping Power Revenue down a black hole?



There must be a better way…

The Synergy with Algae:

Roller-Film Algae Cultivation Plus Oxyfuel

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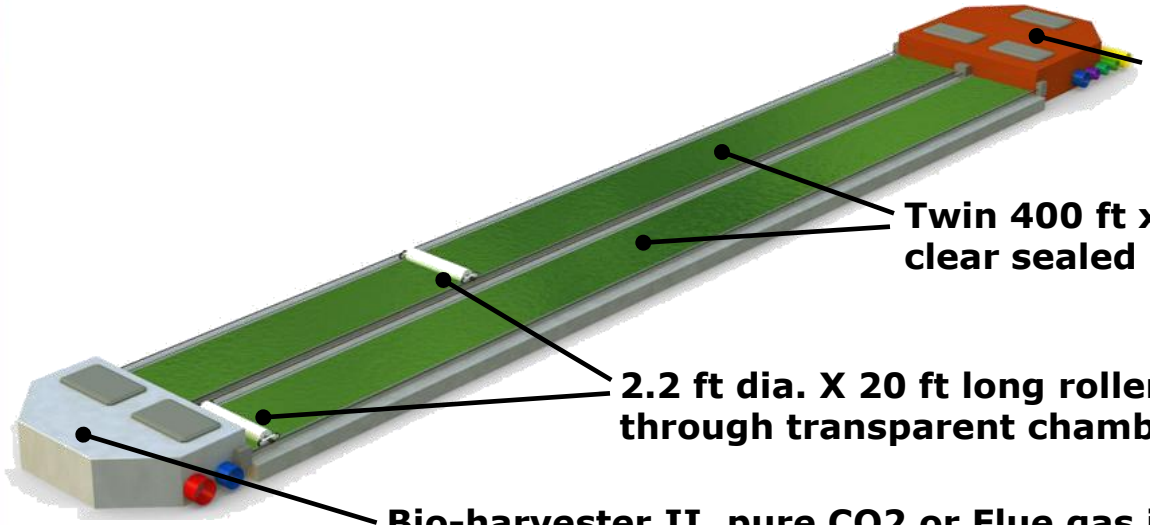
Roller-Film Closed Photobioreactor module



- **Footprint: ½ acre each, 450 ft long x 50 ft wide**
- **CO2 Consumption: 110 tons CO2/acre-year**
- **Precision Biomass Generation: 60 tons/acre-year**
- **Total Water use: Very Low at 3 inches/year equiv.**

Core Claims: Ave. yearly algal productivity in 2012 = 55 gms-dw/m2-day photosynthetic, 2020 total farm cost $100k/acre

Gas Exchange Mechanism

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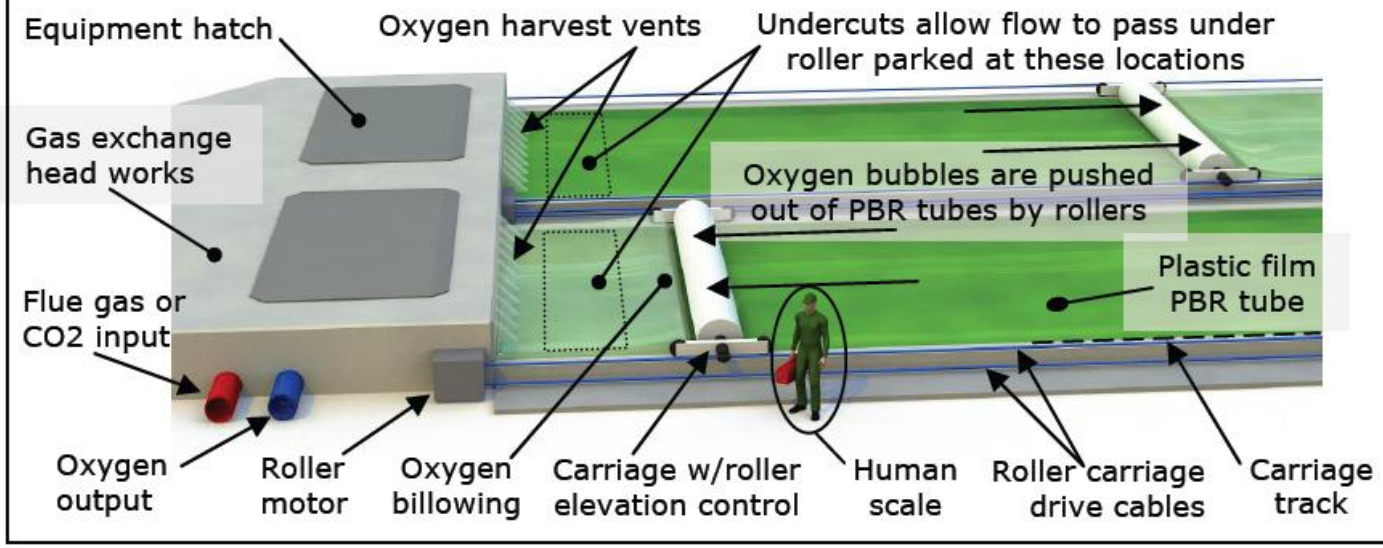
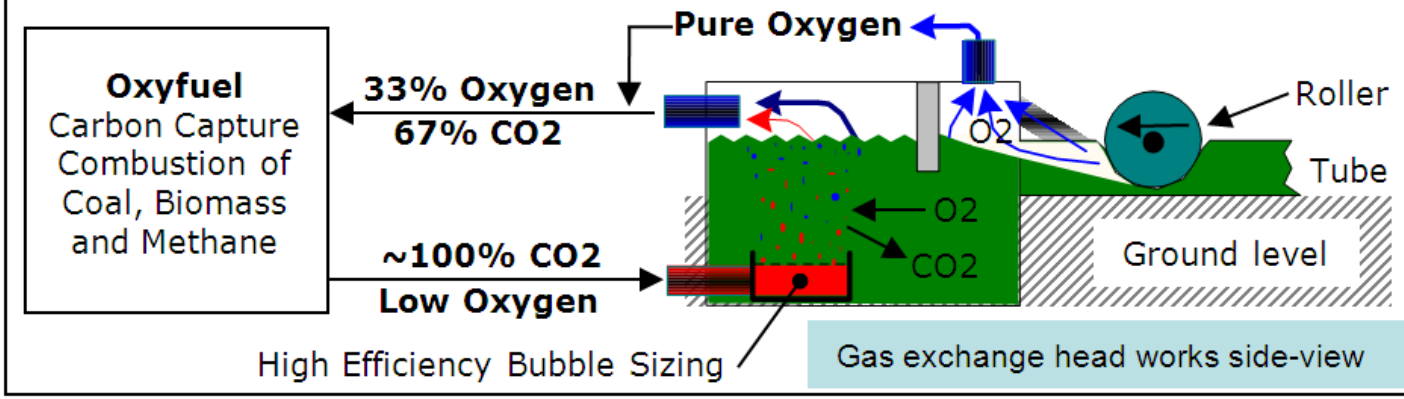
The CC&R Machine is a Roller-Film PBR that Converts CO2 to Biomass and Oxygen



Closed Loop Gas Exchange uses CO2 to Pickup and Safely Carry Oxygen



CO2 Capture and Recycle (CC&R) Farm Layout

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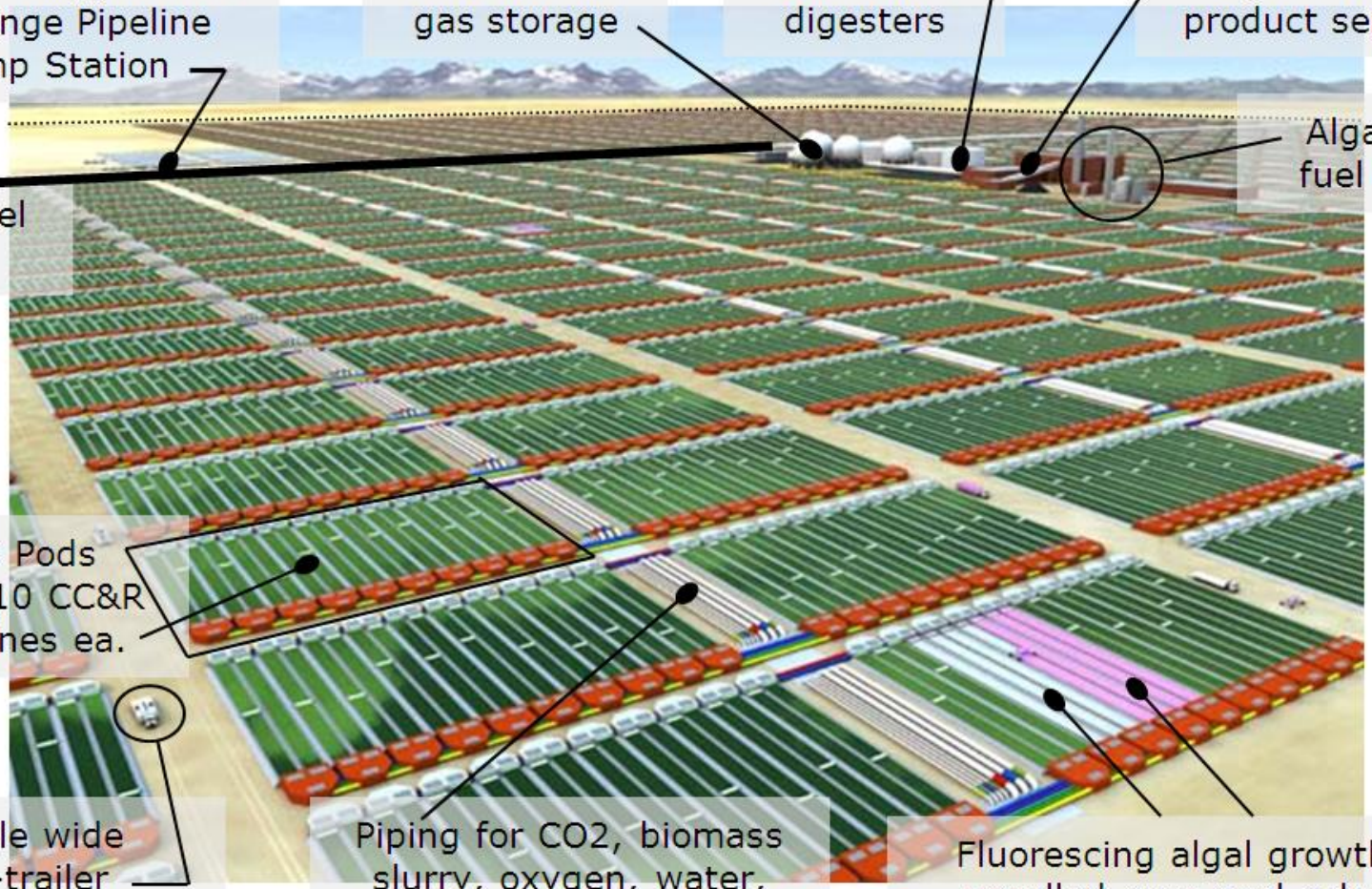
Industrially Reliable, Scalable & Permittable



Coal-Oxyfuel Plant Synergy with Algal CC&R Farm

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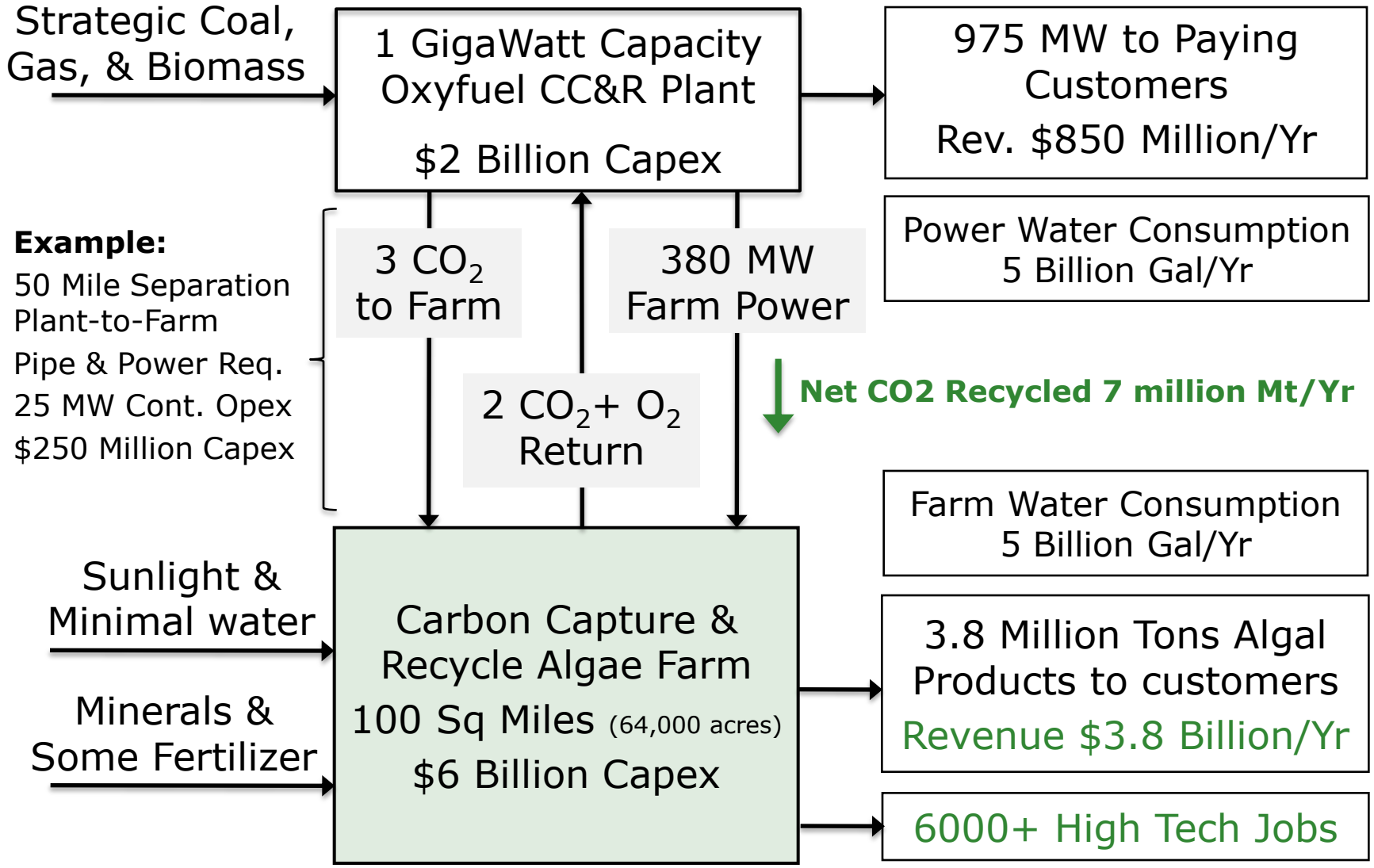


Siting and Regulatory

The Regulatory Landscape: Untested

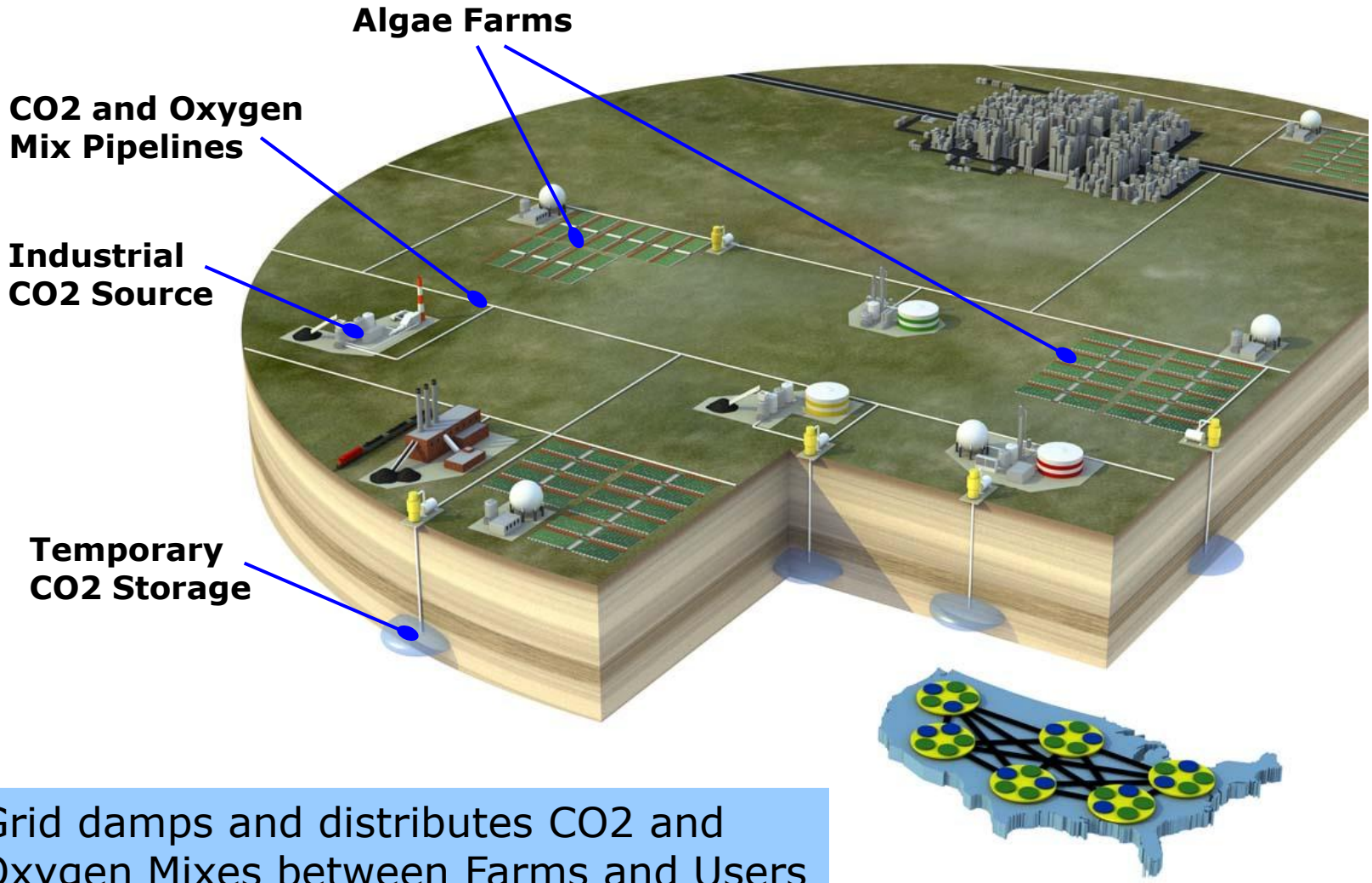
Issues to Watch:

- Use of Genetically Modified Algae
- Algae and Water Use Conversation
- Agricultural Water and Dust Bowl Problems
- Acceleration of Natural Gas Generation
- Foreign Oil and Political Tensions

Initiatives to Watch:

- General Accounting Office Oversight
- Air Force & Mil Alternative Fuel Initiatives
- Coal/Gas/Biomass to Liquids (CTL/GTL/XTL)
- Cap and Trade or Carbon Tax
- CO2 Pipeline Initiatives

Regulatory Eased by National CC&R Pipeline Grid



Grid damps and distributes CO2 and Oxygen Mixes between Farms and Users

Coordination Eased by National Carbon Architecture

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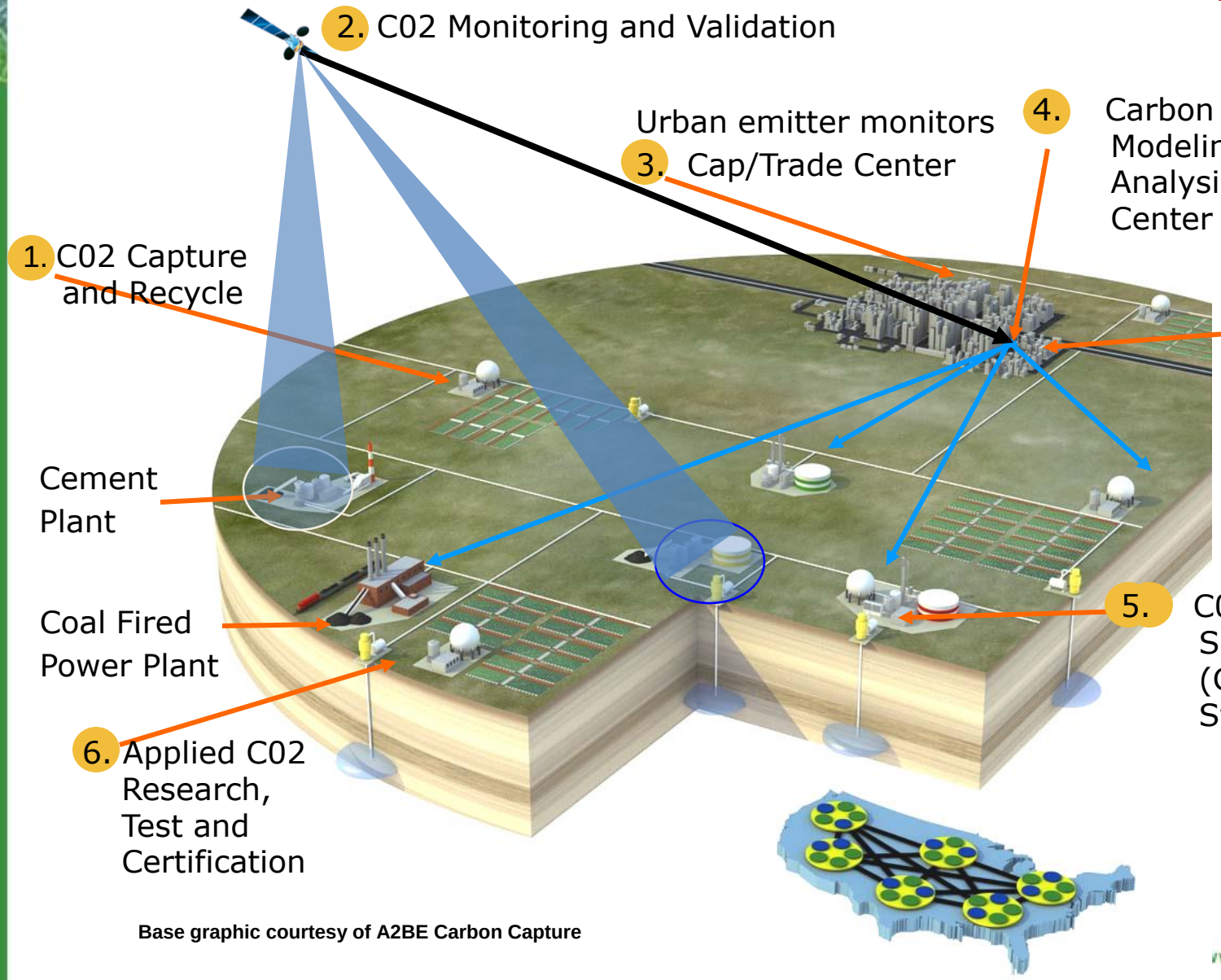
Raytheon

Raytheon Vision for a National Carbon Architecture



Base graphic courtesy of A2BE Carbon Capture

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CC&R Will Reduce Atmospheric CO2

While increasing the standard of living on the planet

Sequestration

- Stable and profitable non-fuel algal products like plastics, waxes, and humic soil improvement permanently capture carbon

Displacement

- Fuels for transportation and industry recycle carbon with solar energy - keeping fossil carbon in ground

Avoidance

- Algal based products can increase industry sector energy efficiencies and avoid BAU* release of CO2 emissions

Uptake

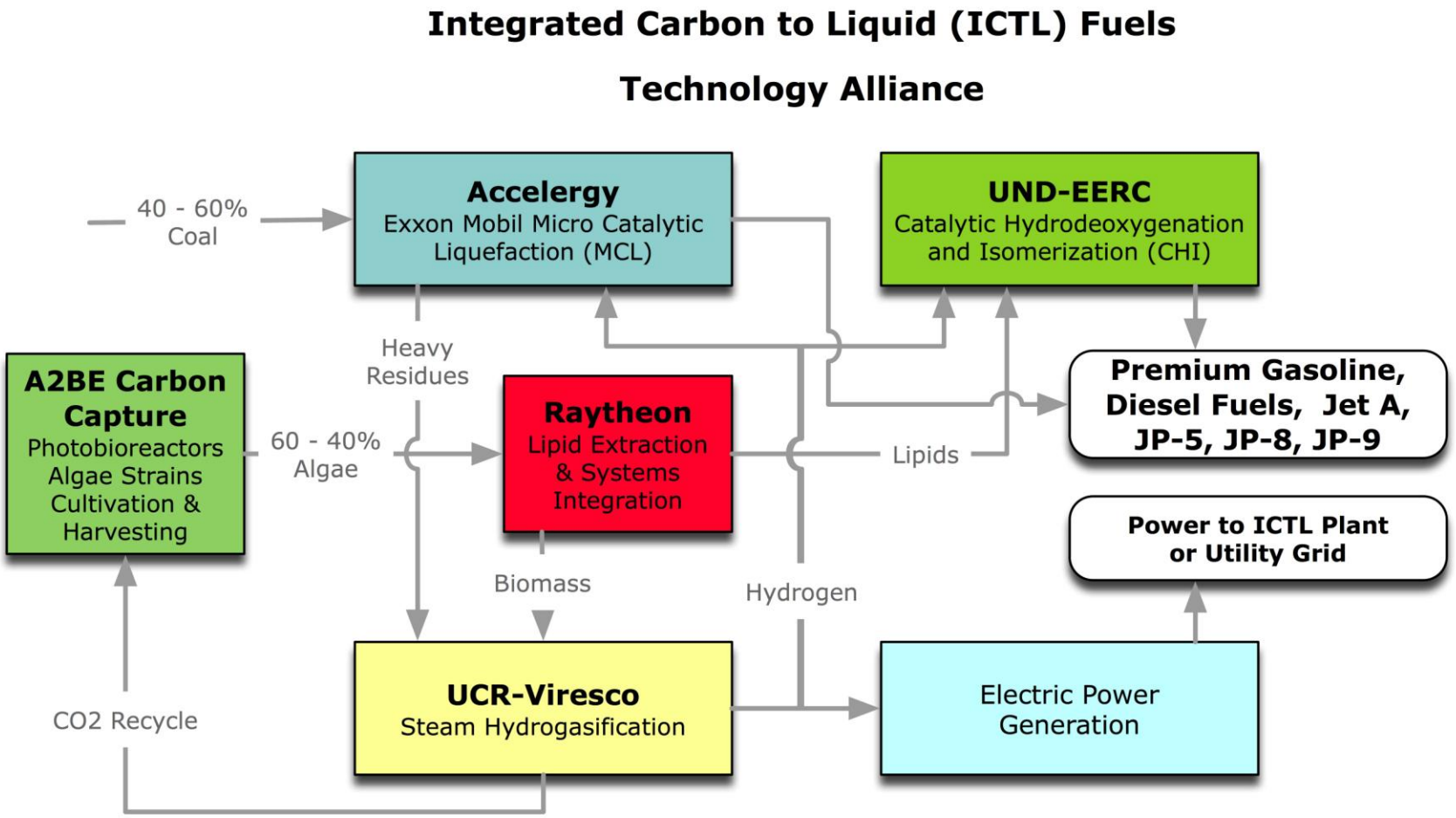
- Algal based soil amendments can vastly enhance soil uptake of atmospheric CO2 and improve land productivity and water retention

*BAU - Business As Usual

Crystal Ball Predictions

The First Initiative Will Be..

CC&R's First Application – Low-Carbon Jet Fuel Alliance



Will Power Generation Alliance be Next?

UND: Univ. of North Dakota
UCR: Univ. of CA, Riverside

Finding More Information

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- Algal Biomass Organization (ABO)

  www.algalbiomas.org

- Commercial Aviation Alternative Fuels Initiative (CAAFI)

  www.caafi.org

- Accelergy

  www.accelergy.com

- A2BE Carbon Capture LLC

  www.algaeatwork.com

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