2015 BIO World Congress on Industrial Biotechnology, Montreal, Canada

Dark Cycle Efficient & Low-Cost Production of Butanol from Carbon Dioxide, Water & Sunlight

“Sustainable Chemistry Powered by the Sun”™

2015 BIO World Congress on Industrial Biotechnology, Montreal, Canada

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Phytonix Value Proposition

• Patented photosynthetic process to produce n-butanol at a cost *substantially below* current commercial methods
  – Estimated total cost = $1.35/gallon
  – Normal butanol (n-butanol) is a valuable industrial chemical and a gasoline substitute
  – **Scalable process.** Low plant CAPEX, high ROI & rapid payback

• **Carbon-negative process**
  – CO$_2$ is consumed and oxygen is produced as a by-product
Cyanobacterial Chemical Production Platform

• Cyanobacteria have the most efficient photosynthetic process of all plants.

• Phytonix’s patented cyanobacterial platform technology enables the low-cost, sustainable production of n-butanol.
  - & other valuable biofuels and chemicals (pentanol, octanol, LCFA’s)

• Proven at lab scale
  – Phytonix has engineered a species of cyanobacteria that secretes 100% n-butanol.
Phytonix Biobutanol Markets

• **N-butanol Industrial chemical market** ≈ $9 billion/yr.
  – Solvents and plastics production
  – Major component of paints, coatings, adhesives and household cleaning products

• **Gasoline fuel additive market** ≈ $140 billion/yr.
  (Currently approved in USA as a gasoline additive at 16%)

• **Gasoline replacement market** ≈ $900 billion/yr.
  **High energy density**: 91% of gasoline, 50% higher than ethanol
  Gasoline engines can run on 100% butanol

The estimated production cost of Phytonix biobutanol at $1.35/gallon will allow it to be sold as a gasoline additive or replacement without subsidies at a high profit margin.
United States Patent No.: US 8,735,651 issued May 27th, 2014
“Designer Organisms for Photobiological Butanol Production from Carbon Dioxide and Water”

Australian patent issued 02/2015. South African patent issued 04/2015. Patents expected to be issued in 2015: Canada, EU, Eurasia, China, India & Malaysia

IP coverage
No IP coverage
Photosynthesis in plants, such as algae and cyanobacteria, typically produces sugars from CO$_2$ using energy from the sun.

Phytonix’s patented technology enables the engineering of cyanobacteria to directly produce n-butanol instead of sugars from CO$_2$, with oxygen as a co-product.
Microbial Chemical Factories

For every gallon of n-butanol produced, 16.3 pounds (net) of carbon dioxide is consumed.
Photobioreactor example (Algenol)

Phytonix has an expected yield of 83,000 gallons/acre/year of n-butanol.
(Algenol yield ≈ 9,000 gallons/acre/year of ethanol)
• Engineer a carbon fixation pathway of the Calvin-Benson Cycle to increase efficiency of the dark cycle carbon fixation process through the overexpression of a key carboxylase (an enzyme that catalyzes the addition of a carboxyl group to a specified substrate).

• Our “Alberta Organism” project is focused on the design and engineering of the host organism, *Synechocystis salina*, ideal for growing in Canada’s climatic conditions of colder temperatures, lower levels of sunlight, and in the brackish water common to oil sands fossil extraction industrial sites.
Cold ecosystem cyanobacteria: *Synechocystis salina*

- Habitat: brackish water habitat, non-marine
- Optimal water temperature range: 8.58 degrees C - 13.71 degrees C

Adaptations for cold ecosystems: certain cyanobacteria have mechanisms that allow them to tolerate and continue to grow in the cold and to tolerate freeze–thaw conditions:

To maintain membrane fluidity at low temperatures, polyunsaturated fatty acids with decreased chain-lengths are incorporated into the membrane.

The production of compatible solutes (e.g., trehalose) helps to reduce the freezing point of the intracellular fluid. Extracellular compounds such as polymeric substances help reduce ice nucleation around the cells.
Identifying and designing optimal carbon fixation/dark reaction pathways

- Different synthetic pathways were designed for source/sink optimization based on 5000 enzymes and five existing carbon fixation cycles. Four criteria were used:

  (i) Enzyme efficiency, measured as the maximum rate to generate 1 mg of product;
  
  (ii) Energetic cost, which refers to the usage efficiency of the resources regenerated by light reaction, measured in terms of ATP and NADPH;
  
  (iii) Thermodynamically favorable, which means that the total free Gibbs energy required in the reactions is negative; and
  
  (iv) How the synthetic pathway would affect the native pathways in the host organism, taking into account the number of enzymes used in the pathway and the compatibility of the synthetic pathway in the host organism.
Based on these criteria, several potential carbon fixation pathways and their carboxylases were created and examined to increase efficiency of the dark cycle carbon fixation process:

MOG pathway experimental data demonstrated that one specific carboxylase was the most efficient primary CO\(_2\) fixing candidate (carboxylase: an enzyme that catalyzes the addition of a carboxyl group to a specified substrate).

Overexpression of genes for this carboxylase’s production results in increased carboxylase protein levels producing enhanced efficiency of dark cycle carbon reactions, carbon fixation and photosynthesis.
Land Required to Displace US Gasoline Annual Usage in the U.S.A.

FIRST GENERATION
Corn ethanol

GEN 2
Cellulosic Ethanol

GEN 3
Algae
Algal Biodiesel (2% solar efficiency)

GEN 4
Cyanobacteria

(9% solar efficiency)

The Future of Fuel
Phytonix

(2% solar efficiency)
Phytonix's expected production cost is materially lower than incumbent n-butanol facilities. Carbon dioxide feedstock vs. petroleum-based feedstock, low energy & low operating costs.
The Angstrom Laboratory, Sweden (Uppsala University): Proof of concept completed: developed cyanobacterial prototype with modified butyrate pathway. Currently producing n-butanol at lab scale utilizing carbon dioxide as the sole feedstock.

Cold and low light productive butanol organism in design phase (the “Alberta Organism”).

The Lee Laboratory, Virginia (Old Dominion University): Genomic transformance of amino acid-based n-butanol pathway in high temperature-tolerant host organism.

The Anderson Laboratory, South Dakota (SDSU): Technically detailed soft-sided phytoconverter™ design with back-end butanol separation system.

Collaborative international organizational structure enables “capital-light” innovation and on-site testing.
Development Plan

Prototype Completed

Tech Develop

2016 Milestone: field test @ 1000 gallons/year butanol

JV

Technology Demonstration

2017 Milestone: Pilot production @ 25,000 gallons/year.
2018/19 Milestone: Expand to demo @ 1,500,000 gal./year.

JV

Project-based Commercialization
# Management and Board of Advisors

## Management Team

**Mr. Bruce Dannenberg, Founder, President & CEO**  
Expertise in business development, strategic and financial management, innovation and commercialization, genetics, microbiology, and industrial management. Degrees in Zoology, industrial management (M.S.) and business administration (M.B.A.)

**Mr. Gordon Skene, Exec VP.**  
Former CEO of several technology companies and VC tech fund.

**Technology and IP Team:**

- **Ms. Soody Tronson**, Director, Intellectual Property Law (outsourced)
- **Dr. Peter Lindblad**, Technology Director, Organism Development (outsourced)
- **Dr. Gary Anderson**, Technology Director, Phytoconverter/PBR Development (outsourced)
- **Dr. James Lee, Inventor & Scientist**: Expertise & degrees in photosynthesis, plant physiology, biochemistry, and synthetic biology (Cornell). 15 years at Oak Ridge National Lab.

## Advisory Board

**Dr. Gary Anderson**: Professor of Agricultural & Biosystems Engineering at South Dakota State University. He specializes in the design of photobioreactor equipment for culturing algae and cyanobacteria for chemical and biofuel production.

**Mr. Scott Hickman**: over 30 years of sales, marketing and management experience with companies ranging from startups to Fortune 500 firms, including a 13 year stint with technology pioneer Sun Microsystems. Scott holds an MBA from Harvard Business School and a BS degree in Industrial Engineering from Stanford University.

**Mr. William Tate**: an accomplished senior executive w/ expertise in shaping strategy, improving performance and delivering results. Successfully managed both large and small companies, ranging in size from $20M to over $2.3B, as CEO of a Fortune 500 company.

**Dr. Peter Lindblad**: Director of the Angstrom Laboratory and Professor of Microbial Chemistry and Molecular Biology at Uppsala University in Sweden.

**Mr. Michael Weedon**: Executive Director of the British Columbia Bioenergy Network with 25 years of experience in senior finance and general management positions in industry.

**Dr. Robert Stewart**: Former Biotechnology Manager at Lanxess, Iogen Biofuels and InBev and an expert on renewable routes for biobutanol production.
## Phytonix Plant Economics (e)

<table>
<thead>
<tr>
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<td><strong>CAPEX</strong></td>
<td>$14 million</td>
<td>$70 million</td>
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<td><strong>Annual bio-butanol Production</strong></td>
<td>2.5 million gal/yr.</td>
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<td><strong>Required Footprint</strong></td>
<td>35 acres</td>
<td>325 acres</td>
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<td><strong>Revenue: Butanol @ $6.25/gallon</strong></td>
<td>$15 million annually</td>
<td>$155 million annually</td>
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<td><strong>EBITDA (with contingency)</strong></td>
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<td>≈ 1.3 years</td>
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Phytonix plants are scalable and cost-effective at capacities ranging from 1 million to 1 billion gallons/year of n-butanol.
Potential Industrial Partners Emitting CO\textsubscript{2} as feedstock for Phytonix Biobutanol

<table>
<thead>
<tr>
<th>Industry</th>
<th>CO\textsubscript{2} Produced (tons/year)</th>
<th>Production of Butanol from CO\textsubscript{2} (gallons/year)</th>
<th>Plant Revenue $6.25/gal Butanol ($/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large fuel ethanol facility</td>
<td>200,000</td>
<td>25,000,000</td>
<td>$156 million</td>
</tr>
<tr>
<td>Large natural gas wells</td>
<td>2,000,000</td>
<td>250,000,000</td>
<td>$1.56 billion</td>
</tr>
<tr>
<td>Large steel mill</td>
<td>8,000,000</td>
<td>1,000,000,000</td>
<td>$6.25 billion</td>
</tr>
<tr>
<td>Oil Sands</td>
<td>Very high</td>
<td>Very high</td>
<td>Very high</td>
</tr>
</tbody>
</table>

Phytonix plants are scalable and cost-effective at capacities ranging from 1 million to 1 billion gallons/year of n-butanol. Broad market opportunity. Current price of n-butanol in chemical market $\approx$ $6.25/gallon.
Biochemicals & biofuels from CO₂ feedstock

$9b biochemical, $900b gasoline markets

Low-cost, high-margin process

Scalable technology

Patented and patent-pending technology

World class scientific R&D partners

Carbon negative production process

Viable as a “drop-in” biofuel without subsidies
## Phytonix Future Milestones

<table>
<thead>
<tr>
<th>Year</th>
<th>Milestones</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015/16</td>
<td>• Field test. Produce 1000 gallons/year of butanol.</td>
</tr>
<tr>
<td></td>
<td>• Raise $3.0 million of equity for field test, working capital, and</td>
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<tr>
<td></td>
<td>refinement of microorganisms to produce n-butanol.</td>
</tr>
<tr>
<td></td>
<td>• Develop Phytoconverter™ and butanol separation equipment.</td>
</tr>
<tr>
<td>2016/17</td>
<td>• On-site pilot plant producing 25,000 gallons/year.</td>
</tr>
<tr>
<td></td>
<td>• Technology integration and development.</td>
</tr>
<tr>
<td></td>
<td>• Raise $6-$10 million, mainly from strategic partners &amp; grants.</td>
</tr>
<tr>
<td>2017/18</td>
<td>• <strong>Prove commercial viability.</strong> Expand production to 1,500,000</td>
</tr>
<tr>
<td></td>
<td>gallons/year of butanol for demonstration. Revenue ≈ $9m/year.</td>
</tr>
<tr>
<td></td>
<td>• Capital ≈ $10 million from strategic partners, project debt, equity.</td>
</tr>
<tr>
<td>2019</td>
<td>• Build commercial scale plants at industrial sites emitting CO₂</td>
</tr>
<tr>
<td></td>
<td>• Fund with JVs and project financing</td>
</tr>
<tr>
<td></td>
<td>• Explore international licensing</td>
</tr>
</tbody>
</table>
Phytonix Process Overview

WATER   CO₂   SUNLIGHT

CYANOBACTERIA

MODIFIED PHOTOSYNTHESIS

BIOSAFETY CELL DIVISION

SEPARATION SYSTEM

BUTANOL / PENTANOL

MODULAR PHYTOCONVERTERS™ ORGANISMS SECRETE BUTANOL
Butanol Competition

• **Incumbent fossil-based producers**: BASF, DOW, Eastman, OXEA, etc.
  – expensive, carbon intensive and energy intensive

• **Fermentation/bio-based producers**: Gevo, Butamax (BP/DuPont JV), Cobalt Technologies, Green Biologics
  – biomass feedstock = higher cost, generates CO$_2$ as a waste product

• **Phytonix solar-based production**:
  – no biomass feedstock = low cost, carbon-negative and low energy process
Strategic Partners

Corporations considering partnering/investing with Phytonix include:

- European automobile manufacturer
- European industrial with steel mills and cement plants
- European oil & gas major
- Canadian oil & gas companies
- US commercialization-stage, bio-ethanol producer

Industrial partners emitting CO₂ have indicated willingness to host and fund pilot plants following field testing. Joint ventures for commercial plants will be pursued.
Butanol vs. Ethanol as a Biofuel

- **HIGH ENERGY DENSITY:** ≈ 50% higher in mega joules per liter (MJ/L) than ethanol.

- **LOW EVAPORATION (SAFER):** 7x less evaporative than ethanol

- **CAN BE USED IN UNMODIFIED GASOLINE ENGINES** (with a minor fuel-air injection ratio adjustment): ethanol cannot

- **LOW EMISSIONS (both butanol & ethanol):** No sulfur dioxides, carbon monoxide or particulates

- **BUTANOL CAN BE COMBINED WITH ETHANOL FOR A SUPERIOR FUEL ADDITIVE BLEND:** $140 billion market
Besides butanol, the Phytonix technology platform enables it to genetically engineer patentable species of cyanobacteria that can each produce valuable biochemicals and biofuels such as:

- Pentanol
- Octanol, Hexanol, Heptanol
- Medium & long chain fatty acids:
  - C8: octonoic acid (chemical & medicines)
  - C16: palmitic acid (biodiesel feedstock)
  - C18: linolenic acid (biodiesel feedstock)
Key Patented or Pending IP Components

- Calvin Cycle intermediated production of butanol and other chemicals:
  - synthetic biology, metabolomics, proteomics, and genomics technology for streamlined engineering of gene coding for chemical synthesis pathways resulting in photobiological chemical production and new patentable species.
- Technology to disable competing starch hydrolysis and glycolysis pathways
- Technology to overexpress starch hydrolysis and glycolysis pathways
- Growing organisms that secrete target chemicals in photobioreactor/phytoconverter™ systems
- Cell-division control technology to achieve high yield, static cultures
- Redundant biosafety-guarded technology
Perhaps the most striking improvement on “natural” photosynthesis came from the optimization of source (light energy) versus sink (metabolic capacity) for the production of a target chemical.

The advantage of source/sink optimization was illustrated by the heterologous expression of the proton/sucrose symporter CscB in *Synechococcus elongatus* resulting in a record chemical yield for direct photobiological production (Ducat et al., 2012).

These strains also showed both increased photosynthetic efficiency and dark cycle carbon fixation.
## Biofuel Competitors using Cyanobacteria

<table>
<thead>
<tr>
<th>Joule Unlimited</th>
<th>Algenol</th>
</tr>
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<tbody>
<tr>
<td>Higher production cost</td>
<td>Intra-cellular fermentation, not direct photosynthetic production</td>
</tr>
<tr>
<td>Lower value &amp; margin product</td>
<td>Higher cost, less efficient process. Lower CO₂ utilization.</td>
</tr>
<tr>
<td>No proprietary biosafety mechanisms</td>
<td>Lower value &amp; margin product</td>
</tr>
<tr>
<td>Lower yields due to “over-engineered” organisms</td>
<td>Hard to engineer new organisms</td>
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<tr>
<td>Produces ethanol - 33% lower energy content than butanol</td>
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**Scalable: Phytonix Plant Economics (e)**

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Proprietary Components of the Phytonix Process

- Patentable, engineered species of cyanobacteria that uniquely provide:
  - Direct secretion by microbes of n-butanol from CO$_2$ feedstock
  - Efficient conversion of CO$_2$ to n-butanol;
  - High yield of n-butanol per acre (≈ 6X algae)

- Proprietary photobioreactor system (Phytoconverter™) to grow cyanobacteria and efficiently harvest n-butanol secreted by microbes

- Cell-division control technology to achieve high yield
  - Redundant biosafety-guarded technology

- Dark cycle/Calvin Cycle efficient technology enables increased carbon conversion efficiency suitable for lower light and lower temperature climatic conditions
Valuation & Investor Liquidity

Rising Valuation

Valuation will rise materially as milestones are met:

- 1000 gal/yr. field trial  (2016)
- Pilot 25,000 gal/yr.  (2016/17)
- Small commercial scale plant 1,500,000 gal/yr.  (2018/19)

Valuation potential > $1 billion

Liquidity Options

- Acquisition by major chemical or oil company
- Private equity acquisition (large pension funds, etc.)
- IPO
- Build the company. Pay dividends to investors.

Success at pilot & small commercial scale (2017-18) will facilitate JVs for large plants each with revenue of $50 million to >$1 billion/yr. Prime acquisition candidate.