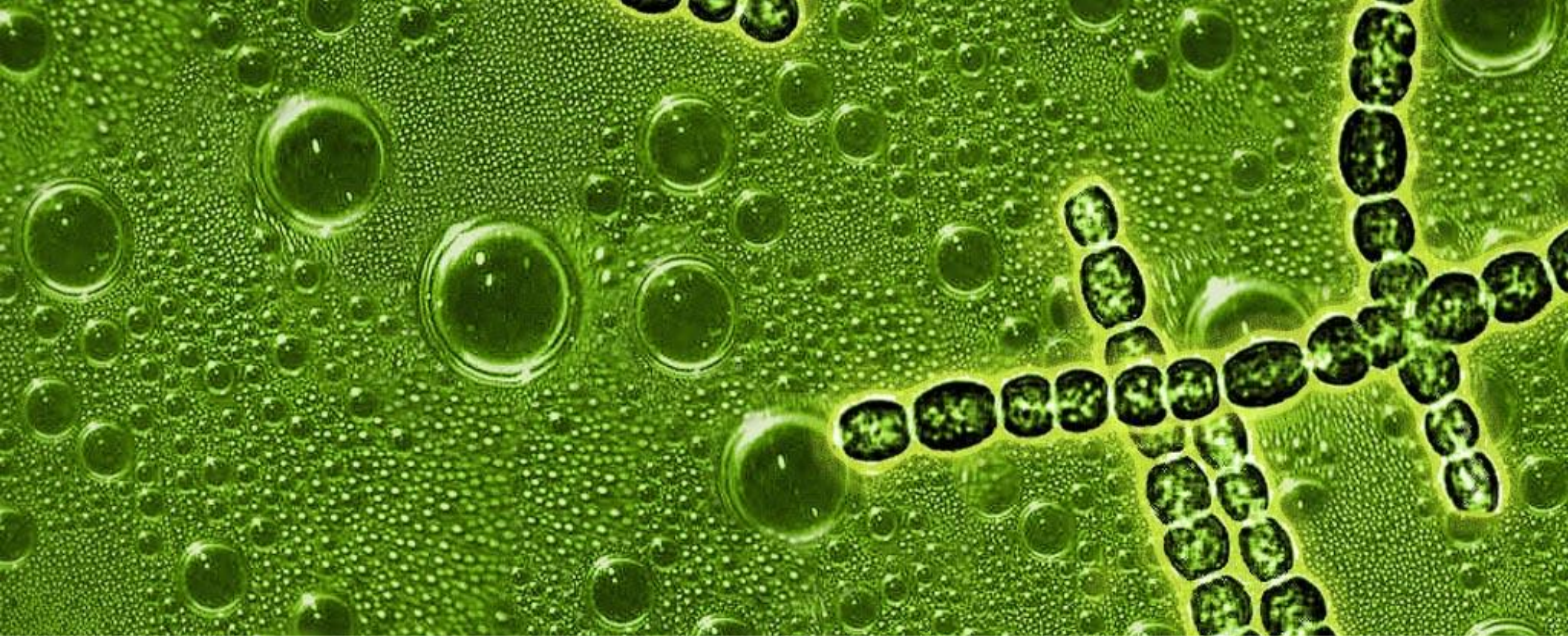

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DOE National Algal Biofuels Technology Review Panel
Cultivation, Resources & Sustainability
July 14, 2016

Algae: Key Resource Input

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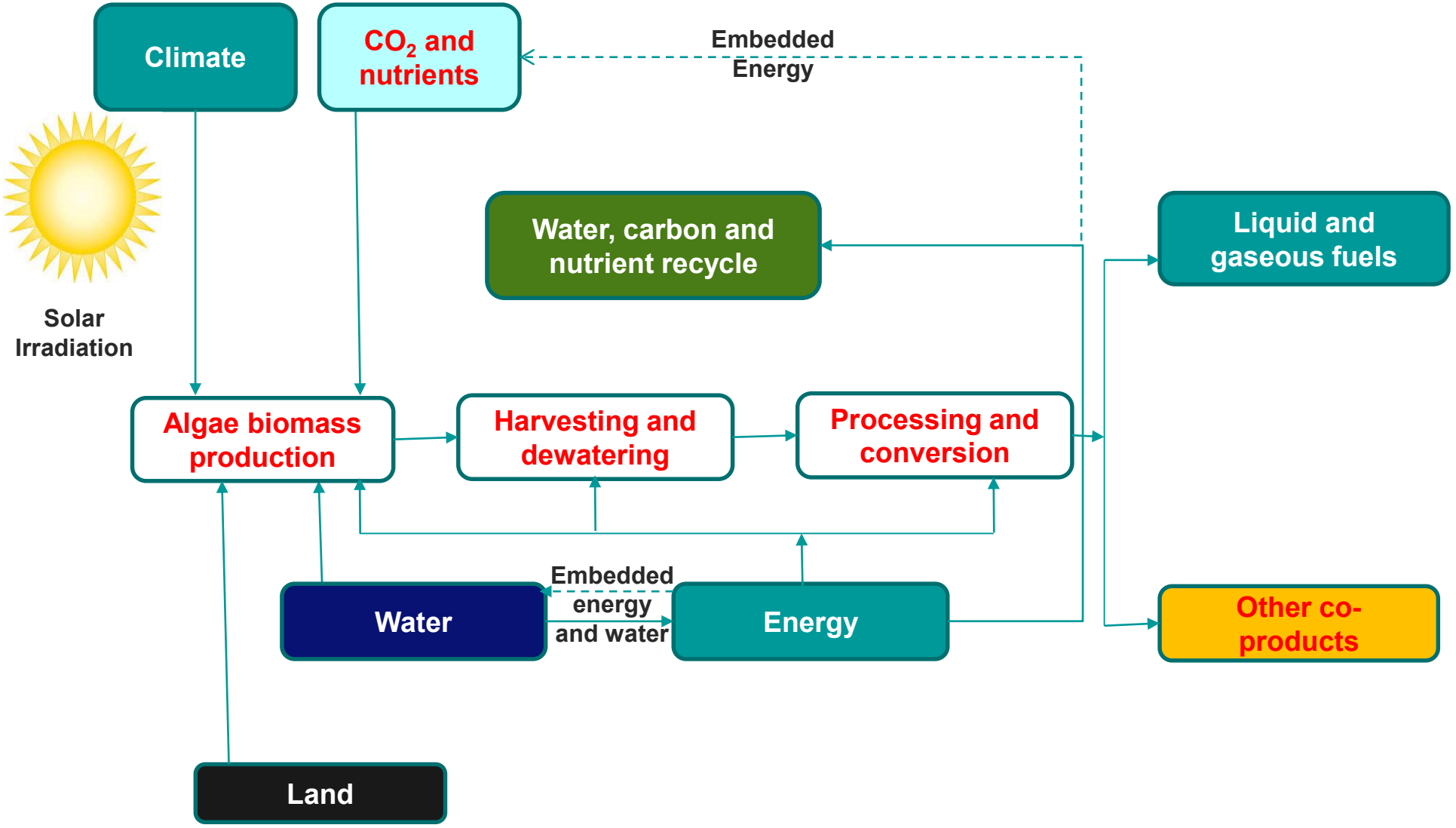

Source: National Algal Biofuels Technology Review, June 2016.

Algenol (photoautotrophic) Platform

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Algenol Process = Sustainable, Minimal Footprint

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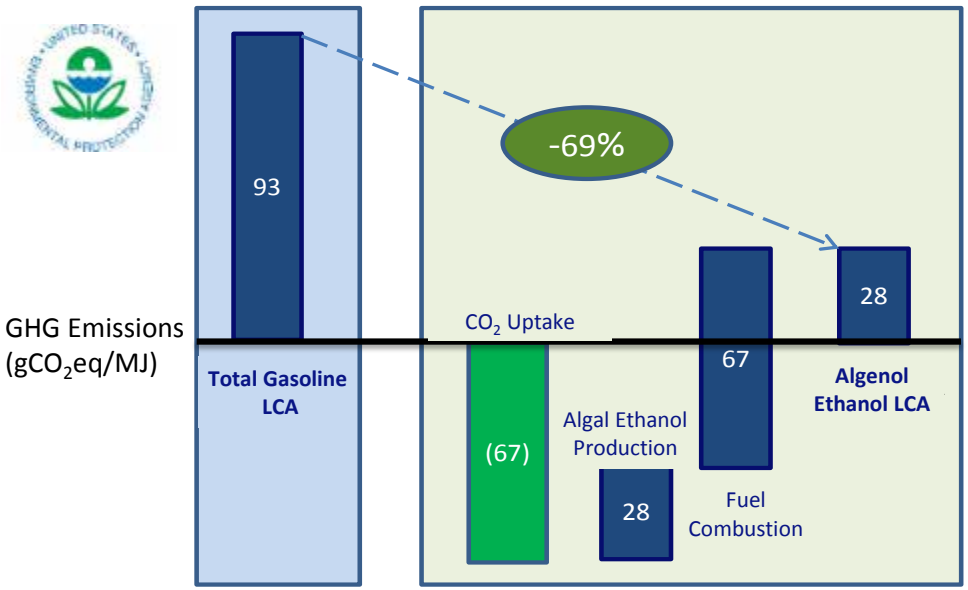
Widely Available Inputs

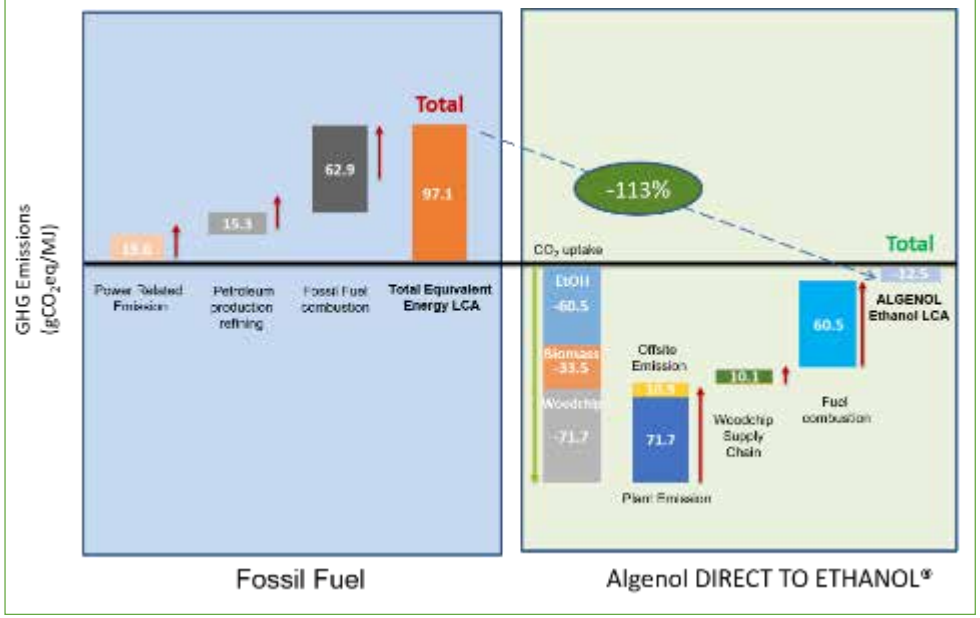


- CO_2 can be sourced from commercial sellers at small scales and from industrial emitters at larger scales
- Saltwater from the ocean, bays or saltwater aquifers does not put pressure on valuable freshwater resources
- Sunshine is abundant across the temperate and tropical zones of the globe
- Minor amounts of N and P are required

Carbon Footprint - EPA approved pathway for D5 RINs



Carbon Footprint – Proposed pathway for D3 RINs



Algenol's Cultivation Progress

Rationale for Photobioreactors

- High productivity.
- Robust environmental controls.
- Less water loss through evaporation

Progress to Date

- Multiple design generations leading to current vertical model & characteristics.
- Developed and optimized PBR manufacturing systems.
- Improved performance and economics of structure, piping and fittings configuration.
- Reduced CAPEX/kg of bio-based product.
- Recent tests & models show total cost/kg fully competitive with open ponds.

Next Steps

- Optimize for multiple algae strains.
- Automate various installation, operation & maintenance facets.
- Further reduce CAPEX.
- Optimize manufacturing for large scale production.
- Secure long term cost advantage versus open ponds for target strains and products.

Low Overall Environmental Footprint

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Factor	Algenol requirements	Scalability and sustainability implications
Climate	Maximize total solar irradiation External temperature within 10° C and 40° C Minimize summer/winter light variability	Latitude and elevation limitations. Strain screening and development can provide enhanced location flexibility in the future.
Water	Algenol current and projected strains use salt or brackish water; some modest fresh water requirements	Photobioreactors need less make-up water than open ponds because of lack of evaporation. Water recycling can exceed 90% with appropriate strategies. These factors, combined with use of brackish or sea water, make freshwater usage essentially a non-issue.
Nutrients	CO_2, N and P	Nutrients requirements will not be a constraint to large scale industry, as long as recycle strategies are implemented. Requires 2.5 tonnes of CO_2 per tonne of biomass produced. Key is permanent shift to flue gas for all products.
Land	No arable land required, but relatively flat profile is essential. PBRs provide enhanced terrain flexibility vs open ponds	Land availability in not a constraint in itself, but needs to be studied in light of climate, water and CO_2 access as well. Furthermore, our productivity levels result in a small overall footprint compared to terrestrial crops.
Energy	Energy required for downstream harvesting, drying, separation and conversion processes	Energy produced far exceeds energy consumed; therefore production is highly scalable.

Future Improvement Areas

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	Indicators	Algenol Today	Algenol Future
Soil quality	Bulk density, nutrient levels	Not applicable.	Not applicable.
Water quantity	Consumptive water use	Salt/brackish water only with up to 90% recycle projected for commercial facilities.	Salt/brackish water only with 90% recycle.
Water quality	Nutrients content, salinity	Salinity +- x % sea water available in most US areas.	Development of strains with broader salinity range.
Greenhouse gases	CO_2 equivalent emissions	69% GHG reduction 85% CO_2 conversion	100+% GHG reduction is possible, in some configurations.
Biodiversity	Quantity and quality of taxa of special concerns	No concerns. Florida state exemption.	National/ International permits.
Air Quality	Emissions	Air, water vapor, CO_2 (minimal)	Minimal.
Productivity	Yield	2X open ponds' productivity for some cyanobacteria strains. 15X ethanol yield vs terrestrial crops.	3X open ponds.

Source: National Algal Biofuels Technology Review

US DOE Research Areas Suggestions

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- Better geological mapping of water quality/algae strain compatibility areas.
- Cost reduction of carbon capture, concentration, transport & short-term (industrial-scale) storage.
- Carbon infrastructure & market models linking carbon emissions and carbon usage sources.
- Demonstration of system integration for CO2 sourcing and biofuel production, including "stand-alone" systems.
- Build interagency support for promising, innovative algae systems and products, e.g. regulatory & funding agencies.