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Algae from Waste Water: a Dynamic Assessment of Canadian Potential

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Project Goals

- Address the question:

  "What are the scales of algae cultivation that might be possible in different regions in Canada based on a geographic assessment of nutrient, solar, and land resources?"

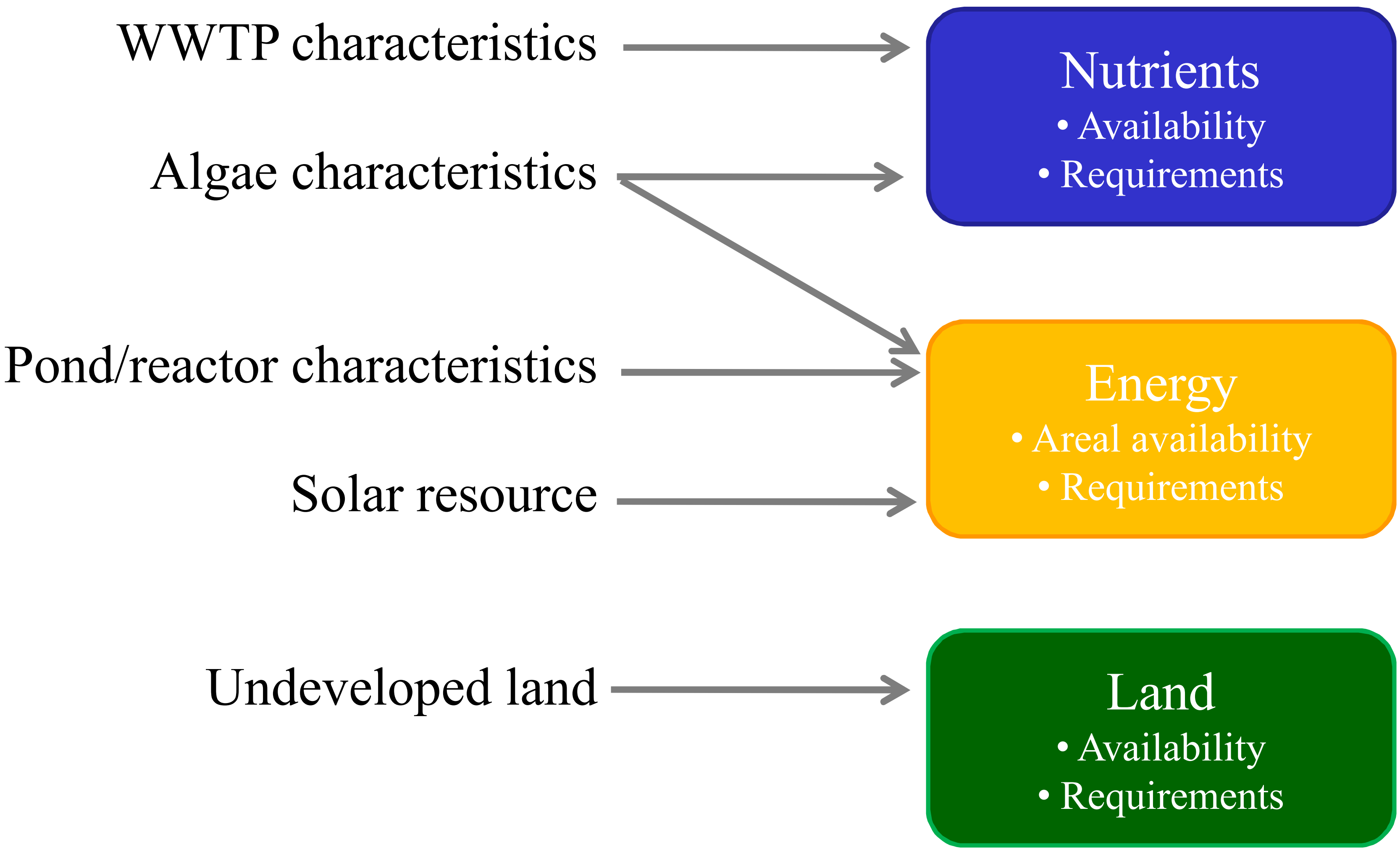
- Create a user friendly computer simulation model that:
  - allows users to evaluate and visualize algae cultivation and biocrude production capabilities in regions across Canada
  - allows users to change assumptions related to nutrient and energy availability and visualize updated output in real time
  - Provide insight into potential siting locations for an NRCC pilot-scale plant

Project Approach

- Assume major nutrients (P, N, and C) necessary for algal growth will come from waste water treatment plants and industrial CO_2 sources.
- Collaborated with NRCC to gather data on municipal effluent and nutrient loads, large CO_2 sources, solar insolation, and land availability in select regions of Nova Scotia, Ontario, Alberta and British Columbia, and assembled it into a geospatial database
- Developed a nutrient module based on stoichiometry of P, N, and C in nutrient sources, and algal requirements for them.
- Developed an energy module based on parameters in Weyer, Bush, Darzins, and Willson *Theoretical Maximum Algal Oil Production,* Bioenerg. Res. (2010) 3:204-213
- Combined these pieces in a single model with a graphic user interface

Model Components

<u>Model Input Data:</u>



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Nutrient Module Inputs

Algae Molecular Composition per Atom P

Adjust numbers in blue. Default for C, N, P is "Redfield ratio". Default for H and O compared to C from Bayless et al 2003.

$$P_{1}\ O_{59}\ N_{16}\ C_{106}\ H_{191}$$

User adjustable ratio of nutrient requirements

Algal Nutrient Uptake Efficiencies:

Nitrogen	100 %	0 % 20 % 40 % 60 % 80 % 100 %
Phosporous	100 %	0 % 20 % 40 % 60 % 80 % 100 %
Carbon	100 %	0 % 20 % 40 % 60 % 80 % 100 %

User adjustable nutrient uptake efficiency

If nitrogen load data are available, or phosphorous load data are available, but not both:

- (selected) Assume missing constituent is unlimited
- Do not calculate productivity potential for that WWTP

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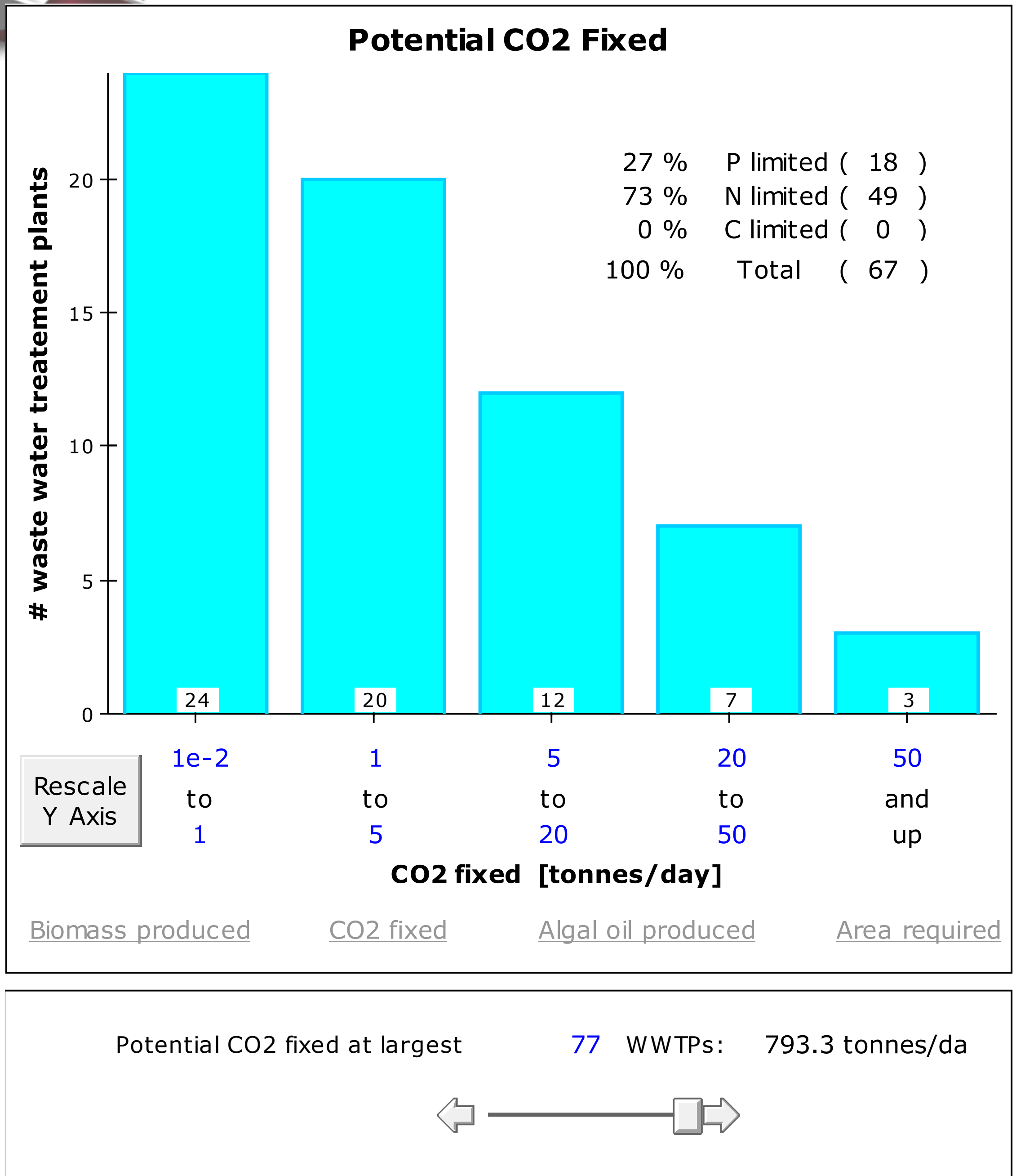
Nutrient Module Outputs



Histogram of # of wwtps that could produce a given range of biomass, or fix a given range of CO_2

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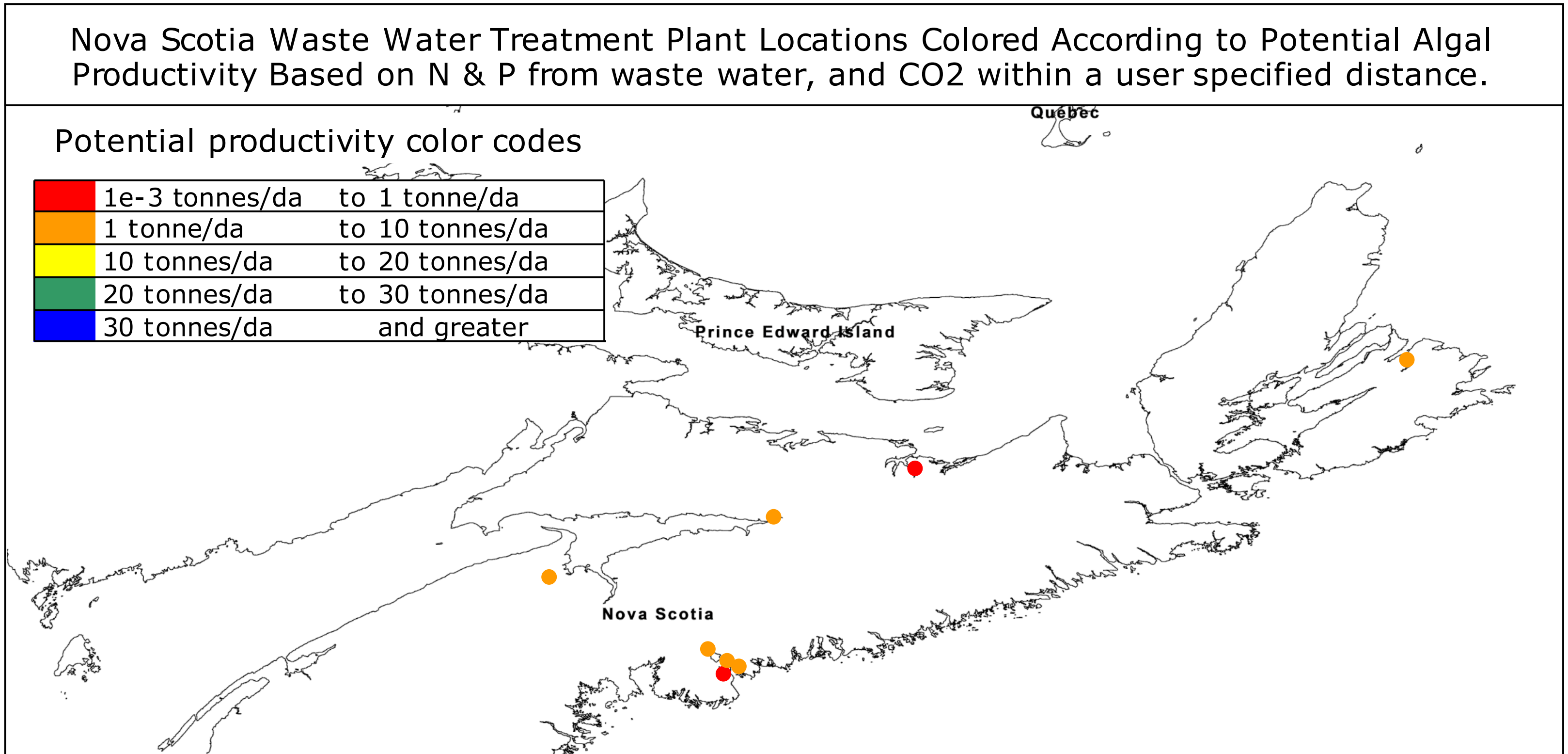
Nutrient Module Output Maps

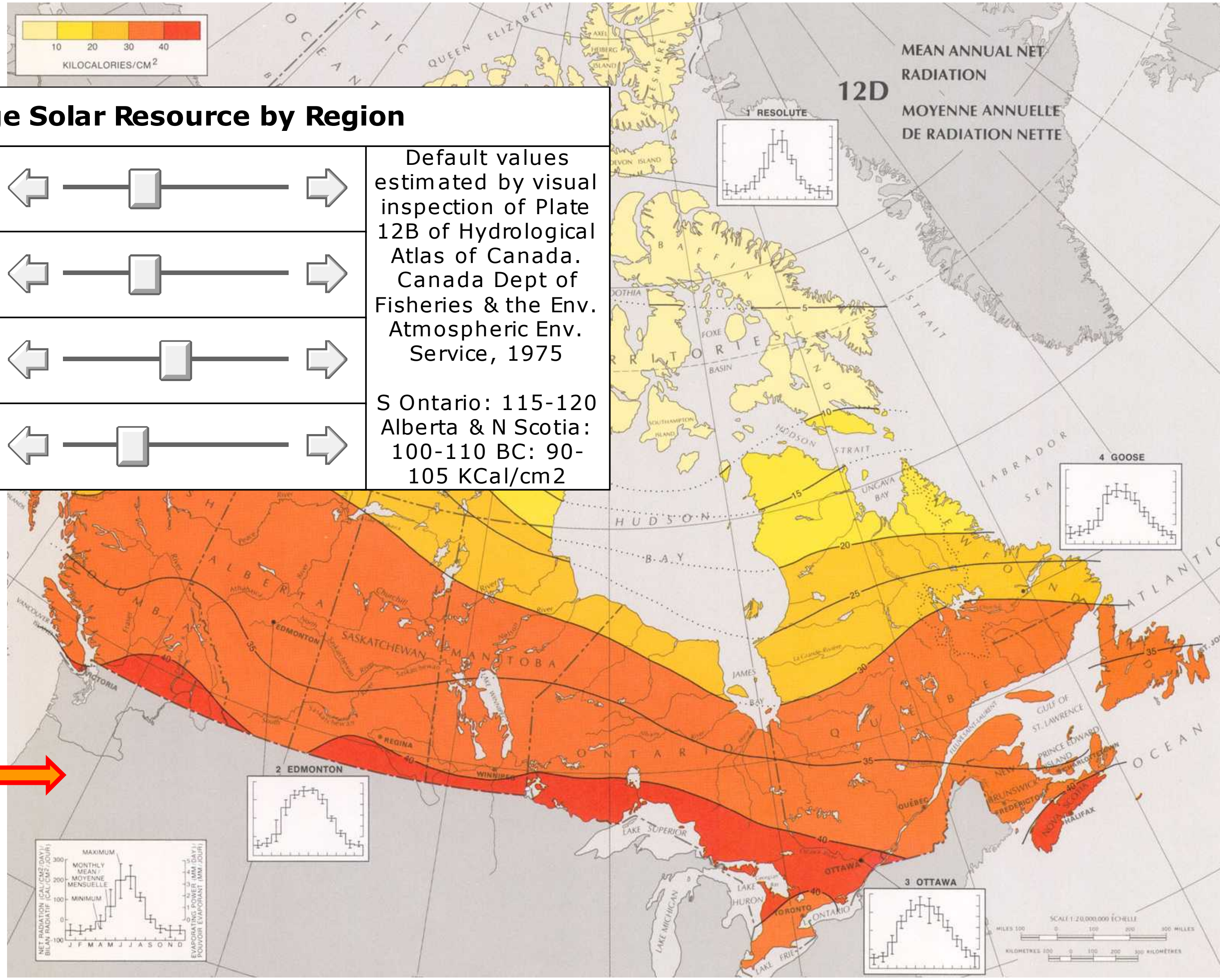
Maps of each region showing location and algal potentials of wwtps



Nova Scotia nutrient limited potential productivities

Halifax - Mill Cove WPCC	6 tonnes/da
Halifax - Eastern Passage WPCP	4 tonnes/da
Halifax - HRM Dartmouth Outfalls	3 tonnes/da
Kings County - Regional STP	2 tonnes/da
County of Colchester - WWTF	2 tonnes/da
Cape Breton - Battery Point TP	1 tonnes/da
Halifax - Roaches Pond PS	8e-1 tonnes/da
East River Pollution Abatement System - East River ECC	5e-1 tonnes/da

Energy Module Inputs



Average Solar Resource by Region		Default values estimated by visual inspection of Plate 12B of Hydrological Atlas of Canada. Canada Dept of Fisheries & the Env. Atmospheric Env. Service, 1975
Alberta	4,393 MJ/m²/yr	S Ontario: 115-120
Nova Scotia	4,393 MJ/m²/yr	Alberta & N Scotia: 100-110
Southern Ontario	4,937 MJ/m²/yr	BC: 90-105 KCal/cm2
British Columbia	4,184 MJ/m²/yr	

User adjustable solar resource estimates with defaults based on map to the right

Energy Module Inputs continued

Algae and environment specific parameters		
Photon utilization efficiency	45 %	Parameters and default values based on Weyer, Bush, Darzins, and Willson 2010 "Theoretical Maximum Algal Oil Production"
Photosynth. quantum requirement	8	
Chemical energy in CH2O	480 KJ/mol	
Biomass accumulation efficiency	50 %	
Biomass energy content	22 KJ/g	
Oil content of algal cells	40 %	
Algal oil density	918 kg/m³	

Photon transmission % by region	
Alberta 75 %	% Photons not lost to reflection. Default values based on extrapolation from Figure 4 in Weyer, Bush, Darzins, and Willson 2010
Nova Scotia 85 %	
Southern Ontario 85 %	
British Columbia 80 %	

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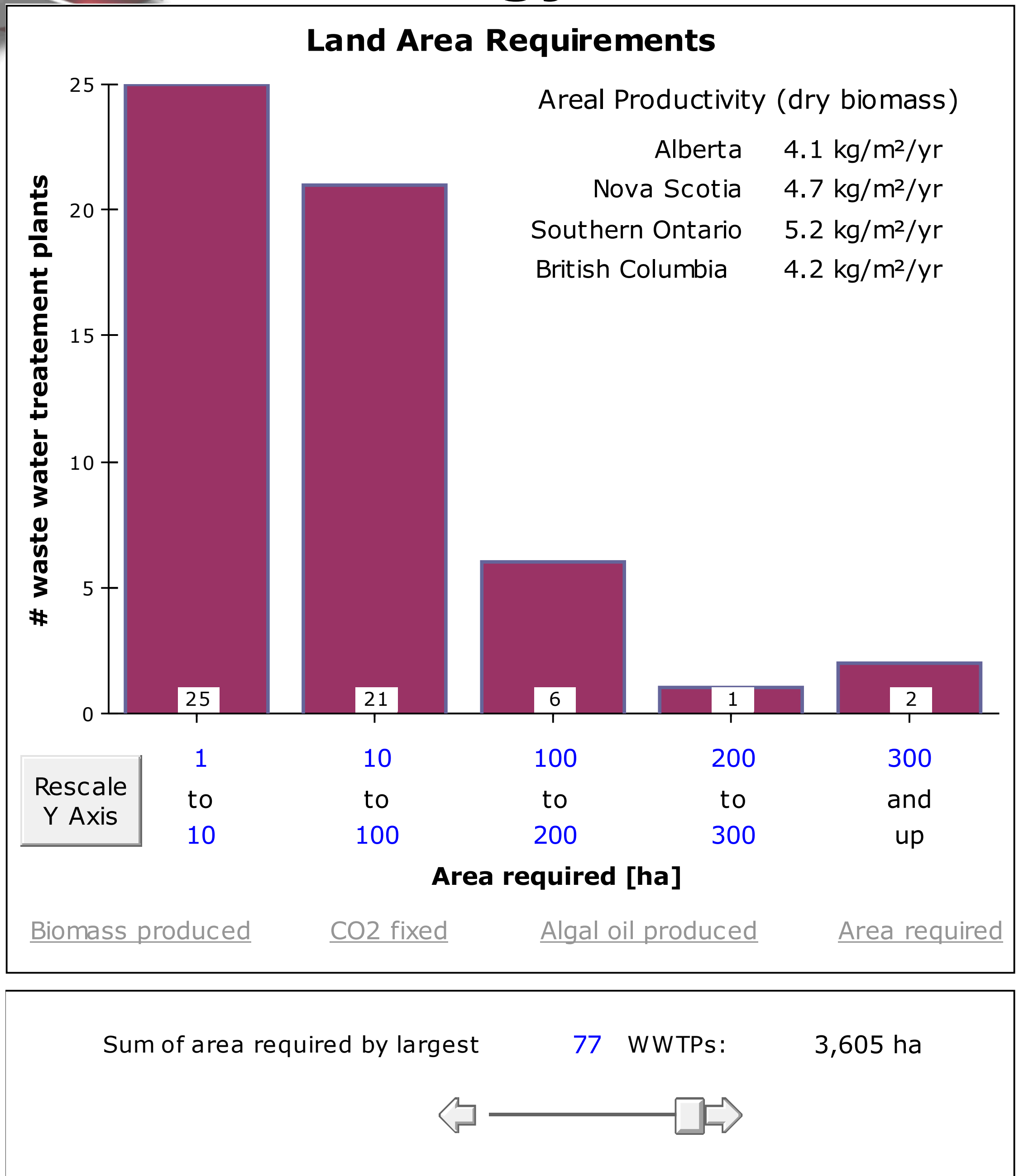
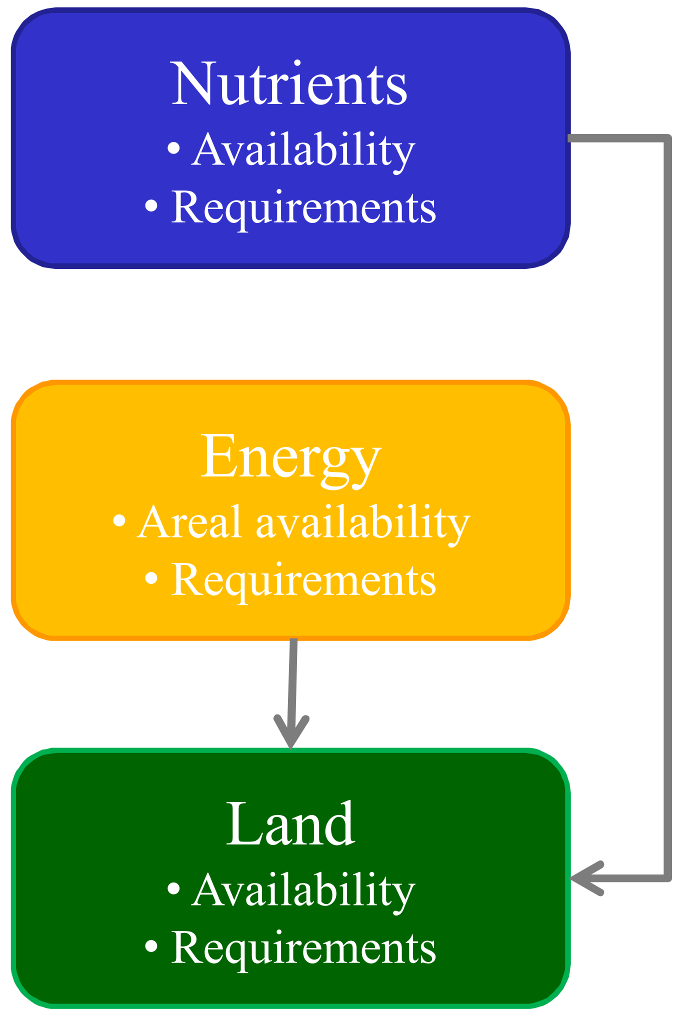
Energy Module Outputs



Histogram of # of wwtps that could produce a given range of biocrude, and how much land that would require

Land availability

Connect nutrient information and energy information with land availability



Land Availability Module

- Non developed land of less than 1% slope classified in GIS.
- (Based on land use, not land ownership due to data availability.)
- Model selects a contiguous area of sufficient size that minimizes the distance between each WWTP and a potential CO_2 source.

1. User selects WWTP for a given region from dropdown

2. Model selects closest land-CO_2 source combination, displays essential properties, and maps all three locations

Nova Scotia WWTP Selector

Kings County

45°4'19.92"	-64°27'34.92"
N load	52 tonnes/yr
P load	? tonne/yr
To land parcel	18 km

CO2 Source

(selected automatically based on WWTP selected at left)

44°40'48"	-63°36'
CO2 Emissions	9.9e5 tonnes/yr
% CO2 Needed	0.11 %
To land parcel	62 km

Land Parcel

(selected automatically based on WWTP selected at left)

44°59'0.94"	-64°15'59.38"
Total area	88 ha
Area required	13 ha
Pot. biocrude	1,688 brls/yr

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Land Availability Module

Select region:

- British Columbia
- Alberta
- Southern Ontario
- **Nova Scotia**

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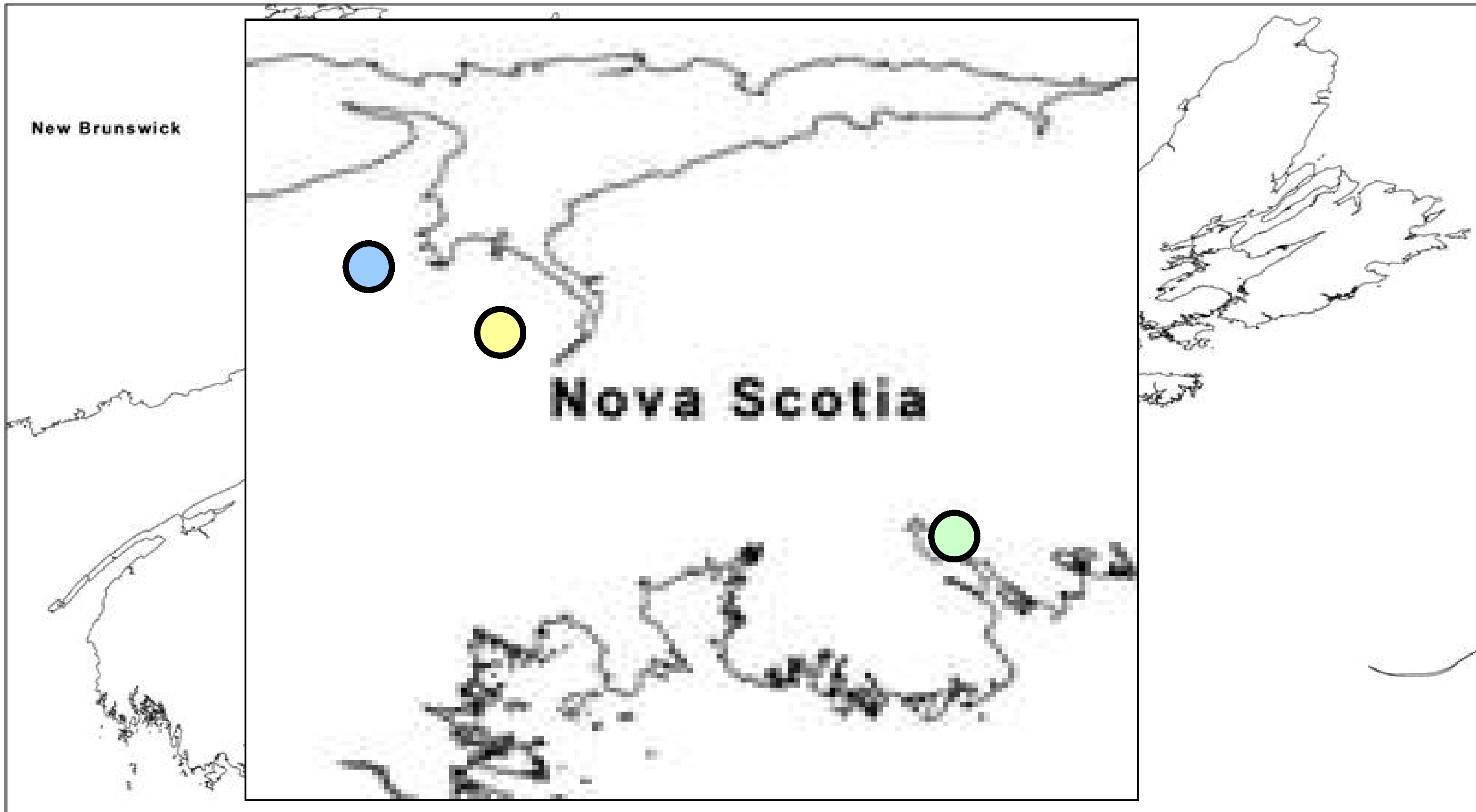
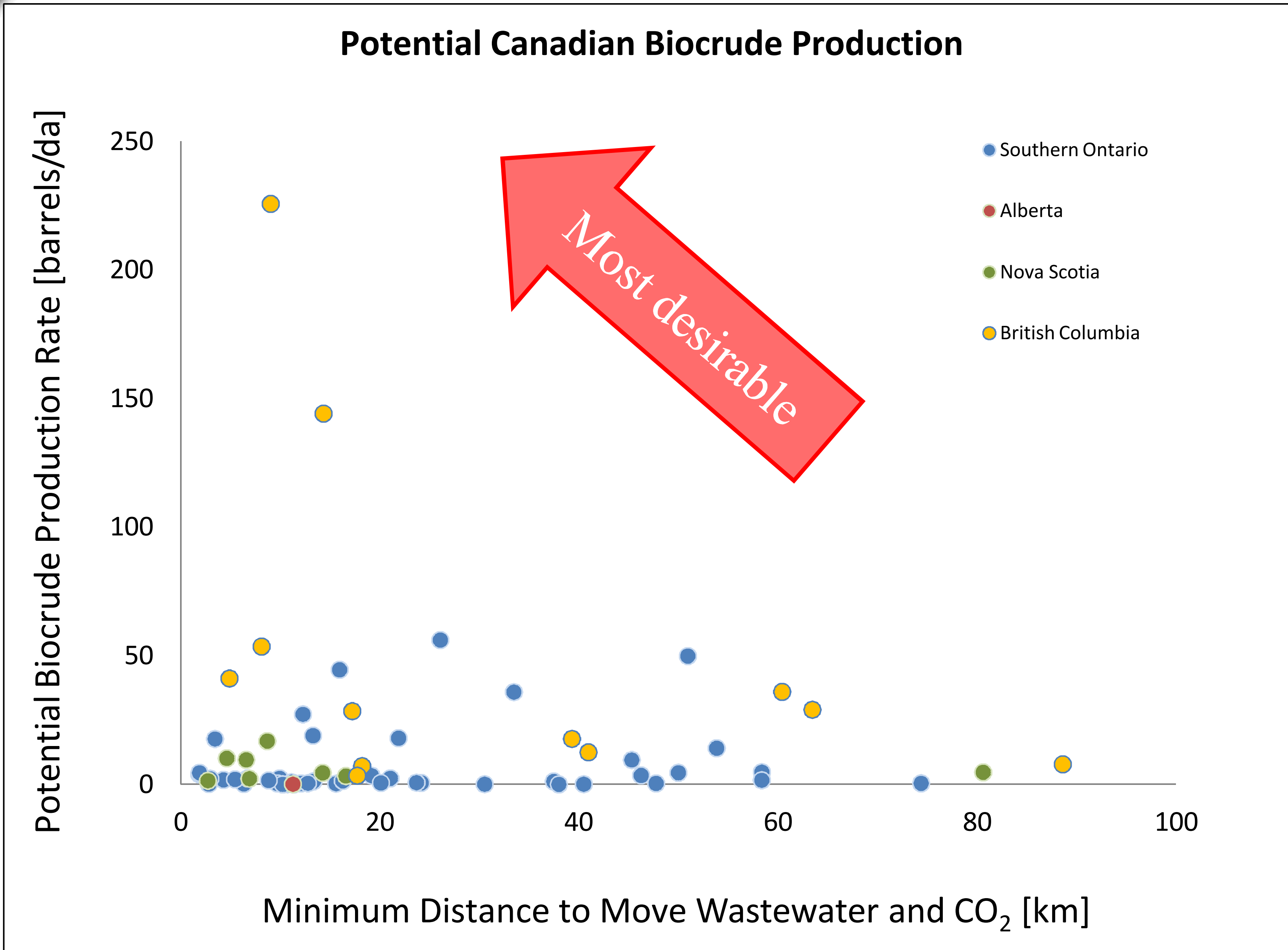


Model Results



Conclusions, Limitations, Next Steps

- Results show that CO_2 is abundant compared to N and P, and thus that nutrient recycling may be critical to large scale feasibility.
- Challenges associated with seasonality of solar resource have not been considered.
- Challenges and opportunities associated with seasonal temperature requirements, and waste heat availability have not been considered.
- Economics are the next big piece to be added to the model.

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Summary

- Project has successfully integrated spatial data and information into a GIS and systems model that evaluates algae cultivation and biocrude productivity potential for locations across Canada
- Nutrient recycling may be critical to large scale feasibility
- Updated/improved WWTP data have been collected, but are not yet in model.
- Contributes to end-to-end, systems understanding of resource needs required for large scale biofuel production
- Creates a framework for similar modeling in other regions and at other scales (current CSIRO collaboration aimed at just that)
- Highlights fruitful and productive collaboration between US national labs (SNL, NREL, PNNL) and National Research Council Canada

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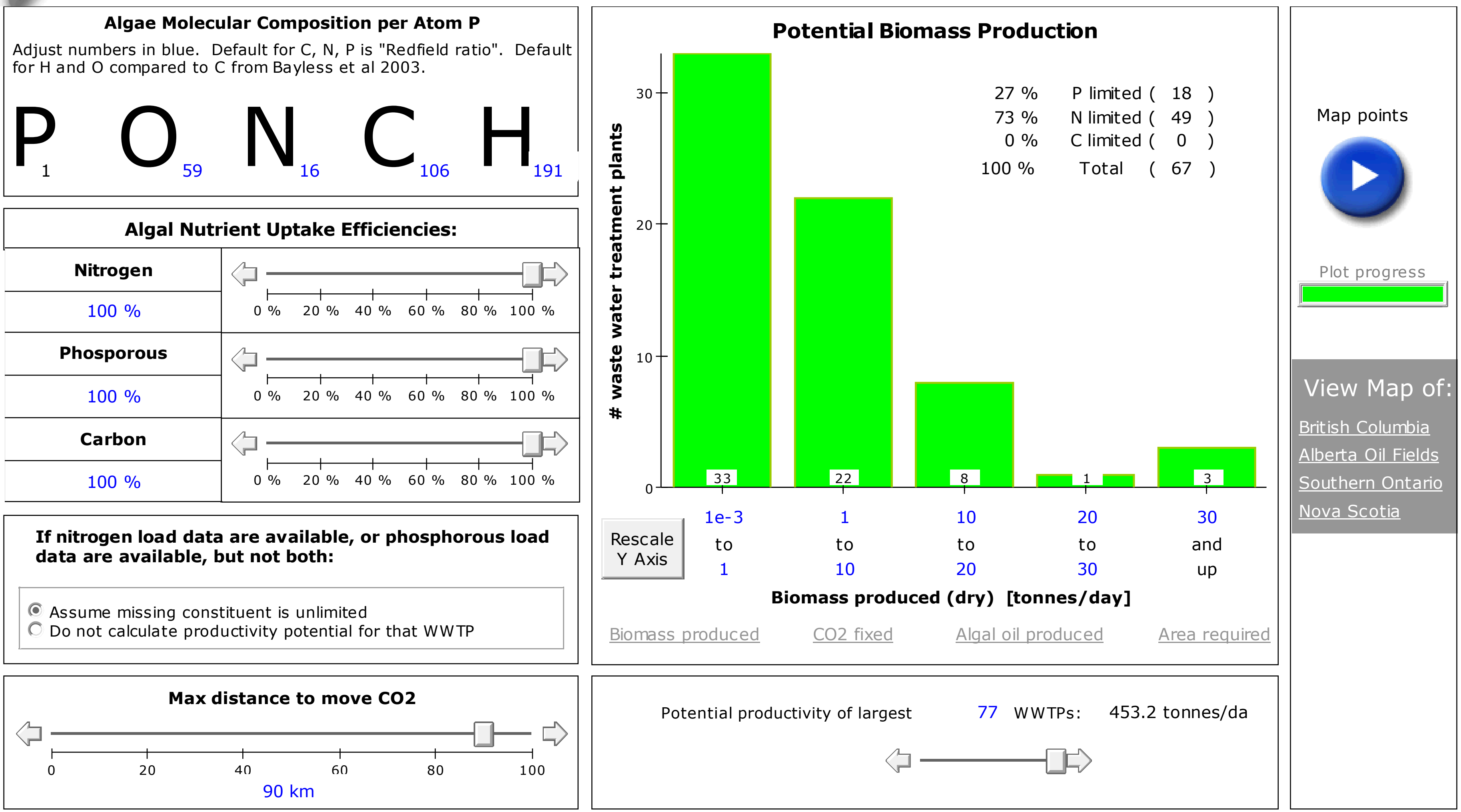
Questions?



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Publications and Presentations

- Canada – US Algal Biofuels Collaboration. Plenary presentation. S.J. O'Leary. Algae Biomass Organization Annual Summit, Phoenix, AZ, Sept. 29, 2010.
- Fuel from Wastewater – Harnessing a Potential Energy Source in Canada through the Co-location of Algae Biofuel Production to Sources of Effluent, Heat and CO2. Poster presentation. G. Klise, J.D. Roach, B.D. Moreland, H.D. Passell, S.J.B. O'Leary, P.T Pienkos, J. Whalen. Algae Biomass Annual Summit, Phoenix, AZ, Sept., 29, 2010.
- Fuel from Wastewater – Harnessing a Potential Energy Source in Canada through the Co-location of Algae Biofuel Production to Sources of Effluent, Heat and CO2. Poster presentation. G. Klise, J.D. Roach, B.D. Moreland, H.D. Passell, S.J.B. O'Leary, P.T Pienkos, J. Whalen. Geophysical Union Annual Fall Meeting December 13-17, 2010
- Algae from Wastewater; A Dynamic Assessment of Canadian Potential. Oral presentation. J.D. Roach, G. Klise, H.D. Passell, B.D. Moreland, S. O'Leary, P. McGinn, E. Hogan, S. Bhatti, P. Pienkos. 4th Congress of the International Society for Applied Phycology. Halifax, Canada, June 23, 2011