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On the Transition to Algal Biofuels

Consequences and constrained optimization

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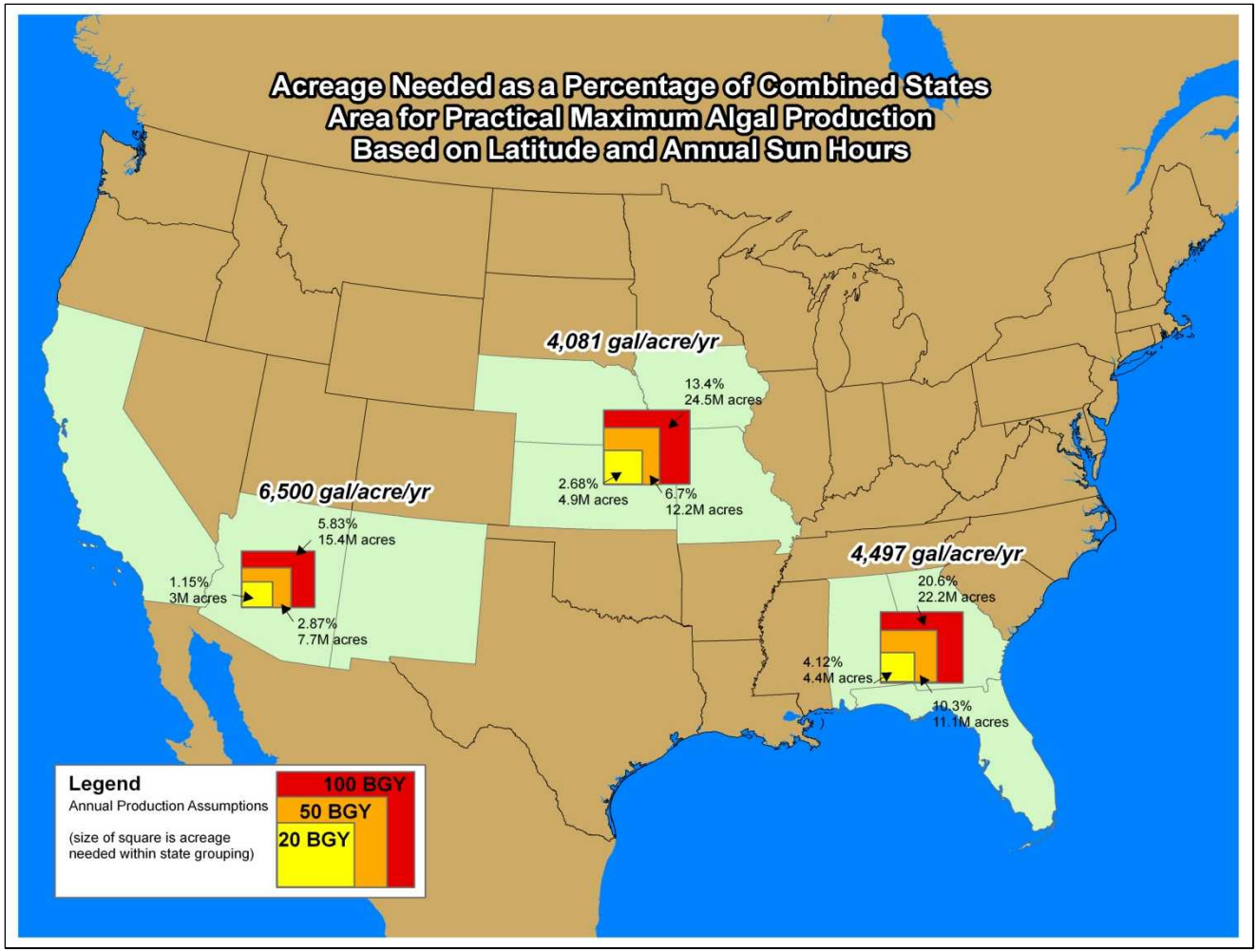
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Setting

- Not concerned with:
  - Unit operations
  - ‘exact’ parameter values
  - Process models
- Concerned with:
  - National scope
  - Objective functions
  - Consequences of overall production
  - Constraints on overall production

National scope: DRAFT GIS feasibility analysis



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Objective functions

- Maximize ?
  - Algae lipid production ?
  - Algae biomass production ?
  - CO_2 capture ?
- Minimize ?
  - Costs (cultivator, processor, consumer) ?
  - LCA effects ?
- Valid objective function(s) are a must!

Consequential analysis

- Determining the consequences of algal biomass/biofuel production
  - Environmental
    - Water consumption
    - Waste streams
  - Financial
    - CAPEX
    - Operation and maintenance

*Simply a rate or level multiplied by a specific parameter, e.g. (CO_2 released per acre of ground cleared) * (acres of ground cleared)*

Constrained analysis

- Determining the consequences of algal biomass/biofuel production constrained by real-world limits
  - Environmental
    - Water consumption limited to available fresh water
    - Waste streams discharge capacity limit
  - Financial
    - CAPEX up to investment resources
    - Operation and maintenance as a function of price and subsidies

A rate or level **constrained to an available resource limit** *multiplied by a specific parameter, e.g. (CO_2 released per acre of ground cleared) * (acres of ground cleared) as acres available decreases over time*

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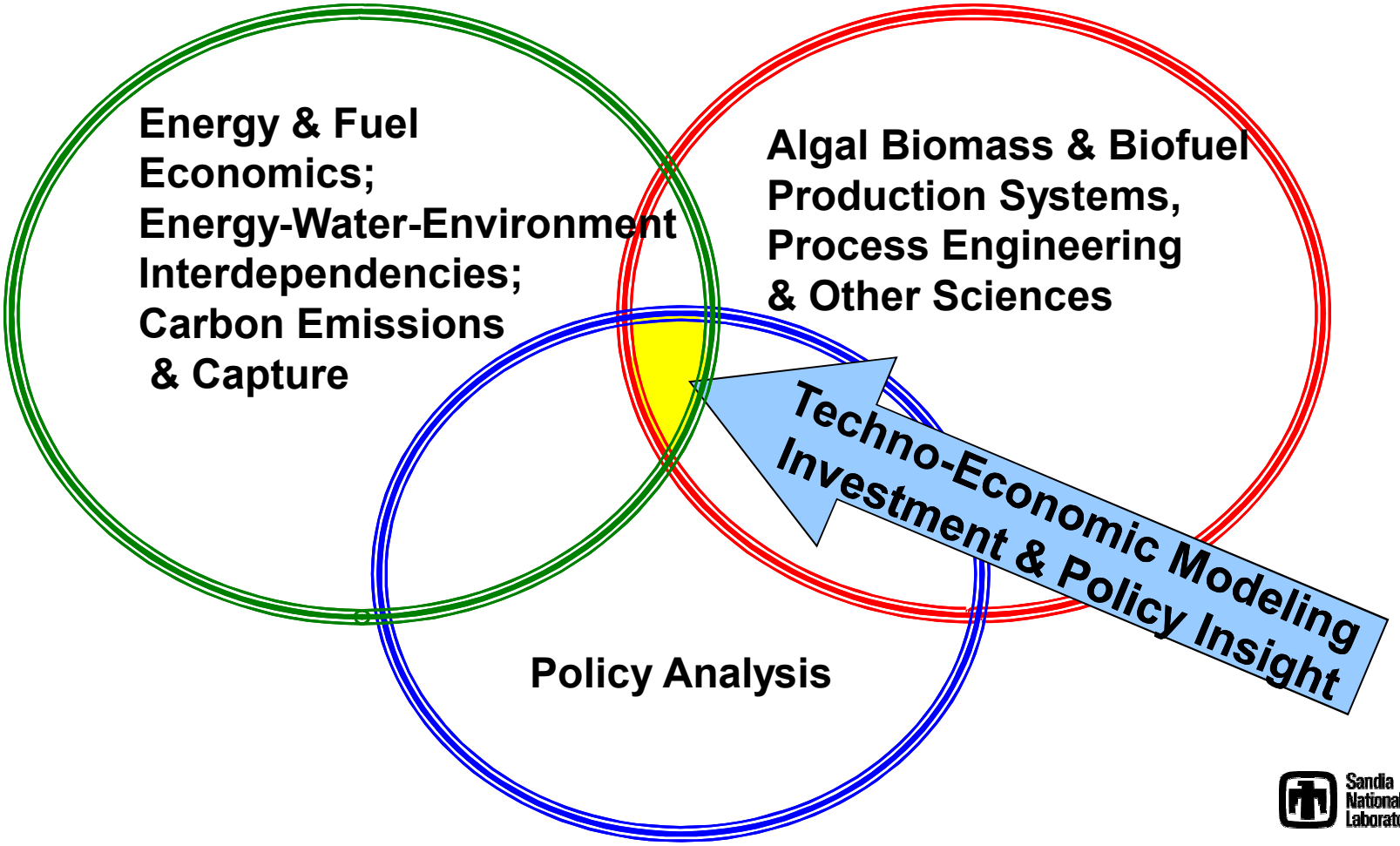
Analysis summary

- Consequential analysis:
  - Relatively simple
  - Requires parameterization of activities
  - Values are typically constants

- Constrained analysis:
  - Relatively difficult
  - Requires parameterization of parameters
  - Requires knowledge of constraints
  - Values can change over time, non-linear
  - Values may be unknown, uncertain

The future of algal biofuel: The intersection of many domains



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Methodology of choice: System Dynamics

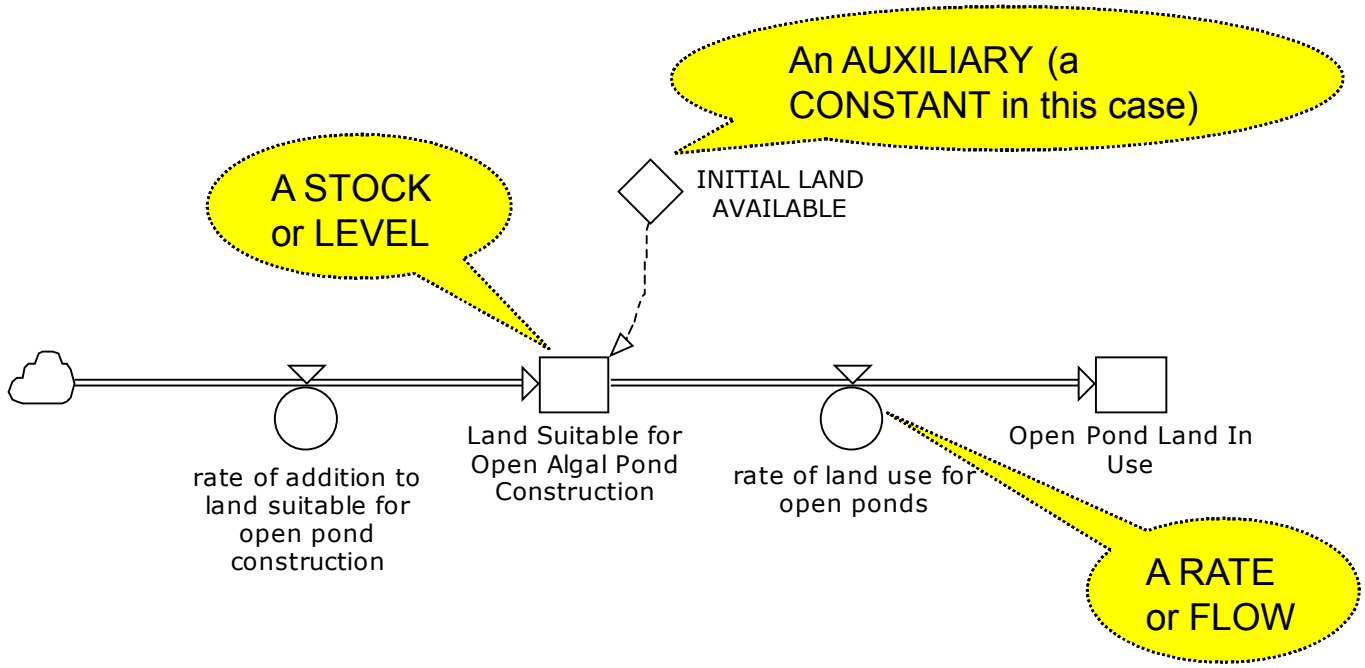
- In Industrial Dynamics [1], Jay Forrester (1961) presents a type of model structure. He indicated that a model should have the following characteristics:
  - Be able to describe any statement of cause-effect relationships that we may wish to include.
  - Be simple in mathematical nature.
  - Be closely synonymous in nomenclature to industrial, economic and social terminology.
  - Be extendable to large numbers of variables (thousands) without exceeding the practical limits of digital computers, and
  - Be able to handle "continuous" interactions in the sense that any artificial discontinuities introduced by solution-time intervals will not affect the results. It should, however, be able to generate discontinuous changes in decisions when these are needed.

1 Now commonly termed System Dynamics.

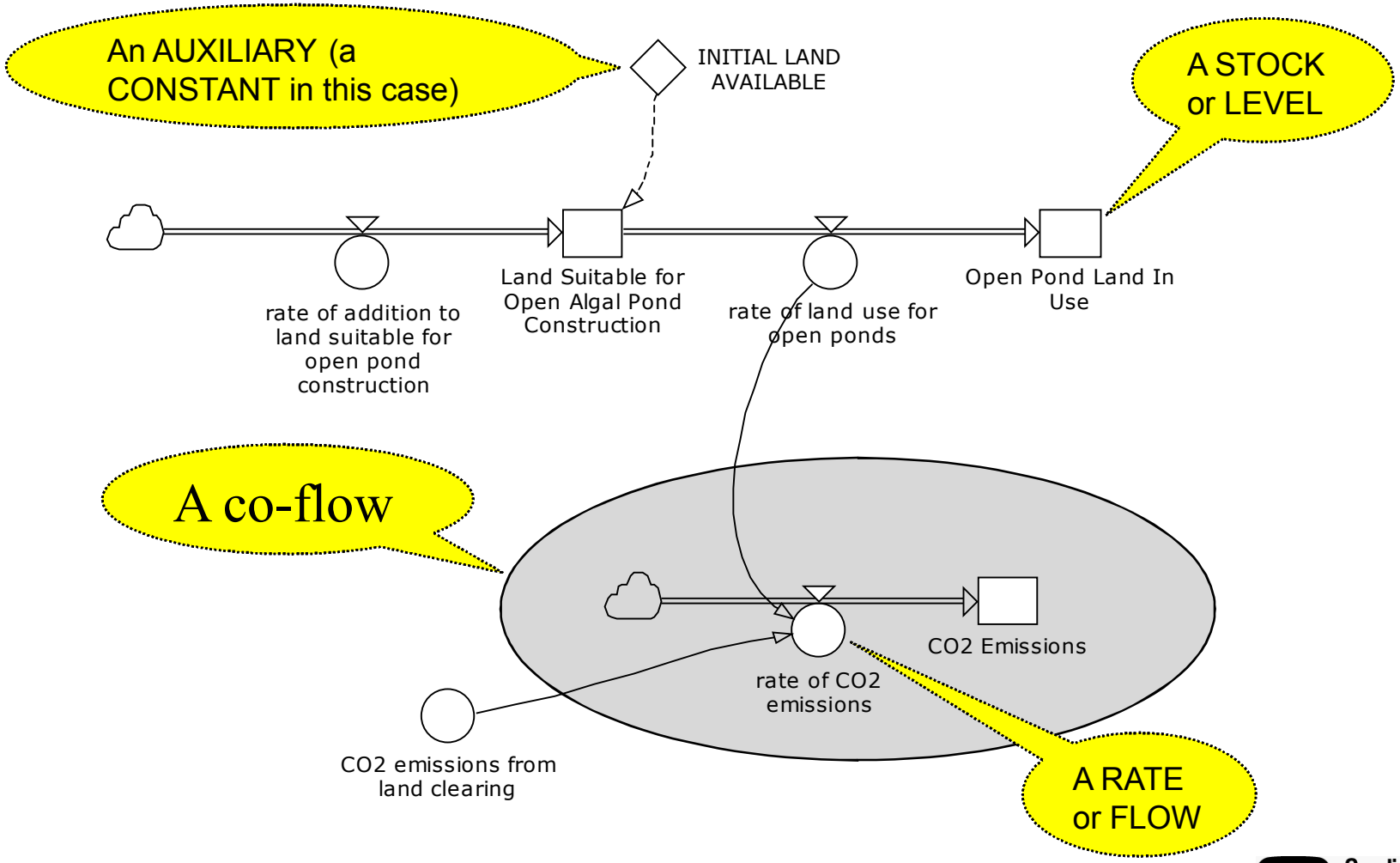
Operationalizing the methodology

- "an alternating structure of reservoirs or levels interconnected by controlled flows."
  - They are made operational by stocks, flow rates, decision functions and information channels.
  - Forrester's proposal has often been metaphorically described as "bathtub dynamics."
  - Stocks are the bathtubs themselves, decision functions are the automated or humanly controlled valves on the flows to and from bathtubs, and the information channels serve as pipes between stocks
  - Feedback is an important feature of these systems

Stock, flow, auxiliary



Characteristics or co-flows



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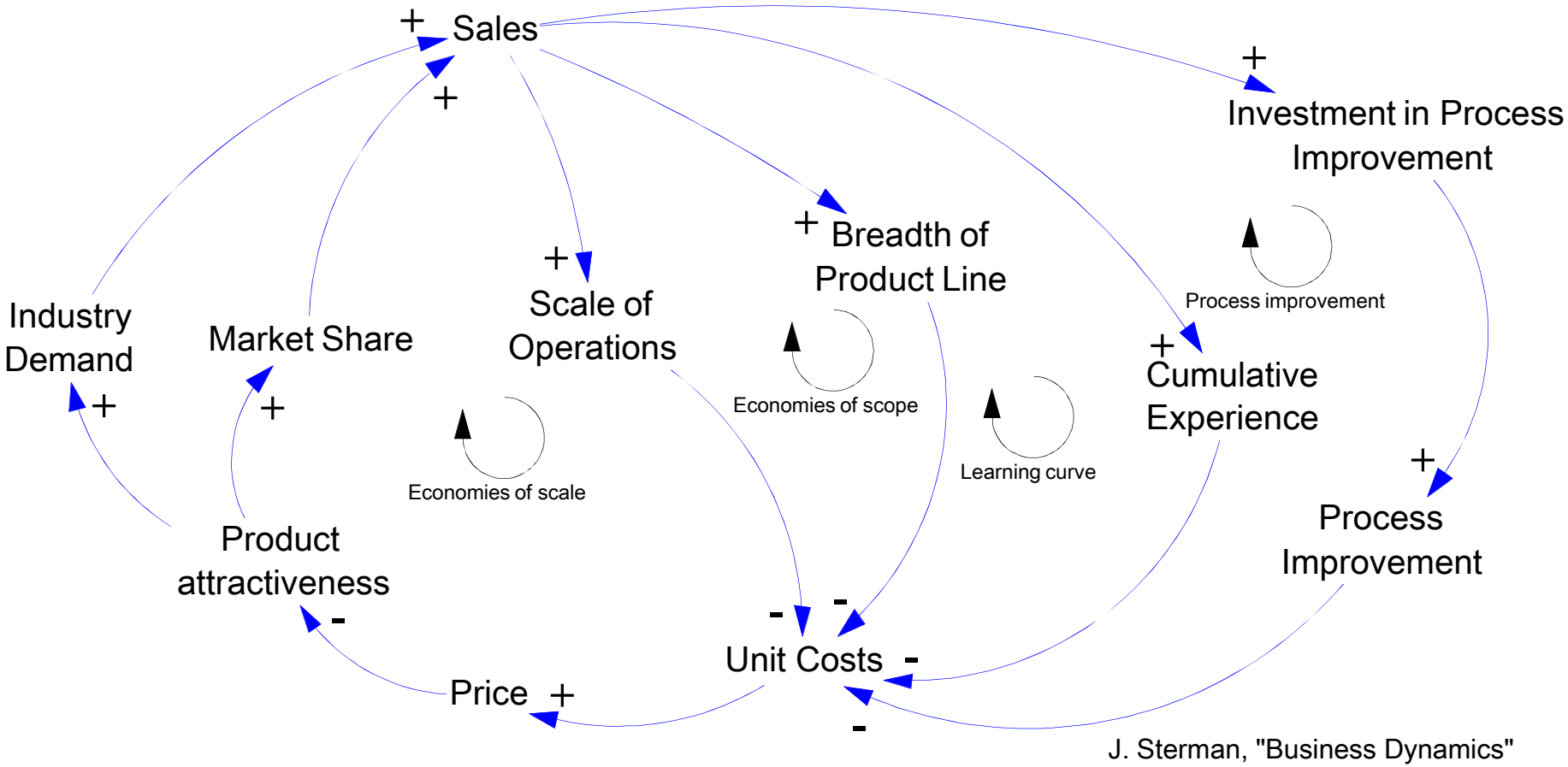
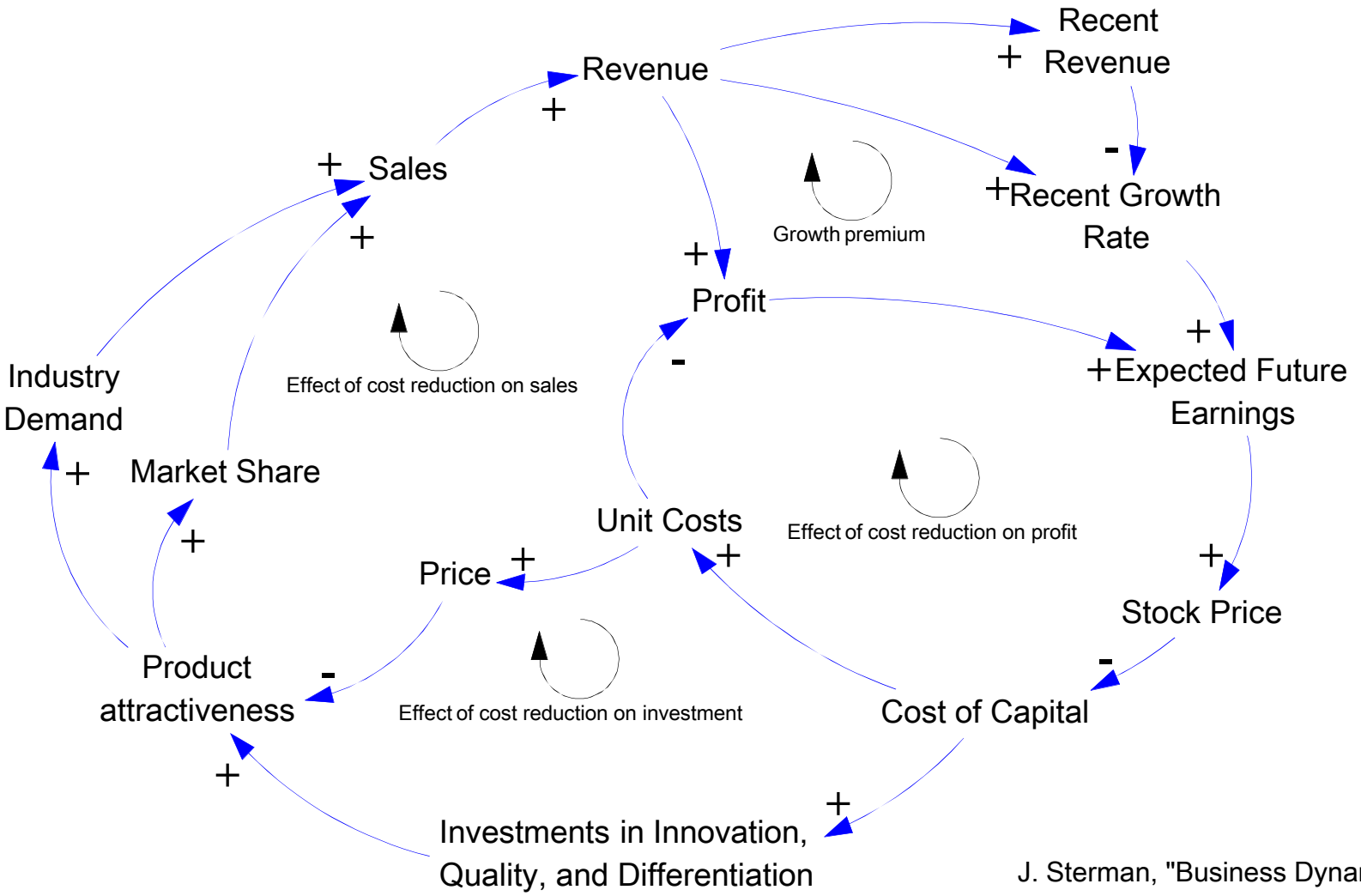
Price and Production Cost



J. Sterman, "Business Dynamics"

Stimulating Growth



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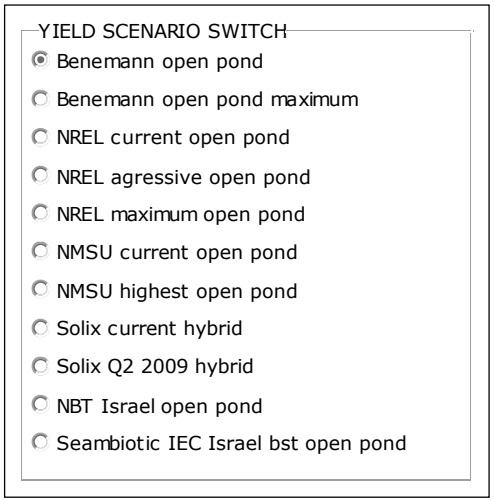
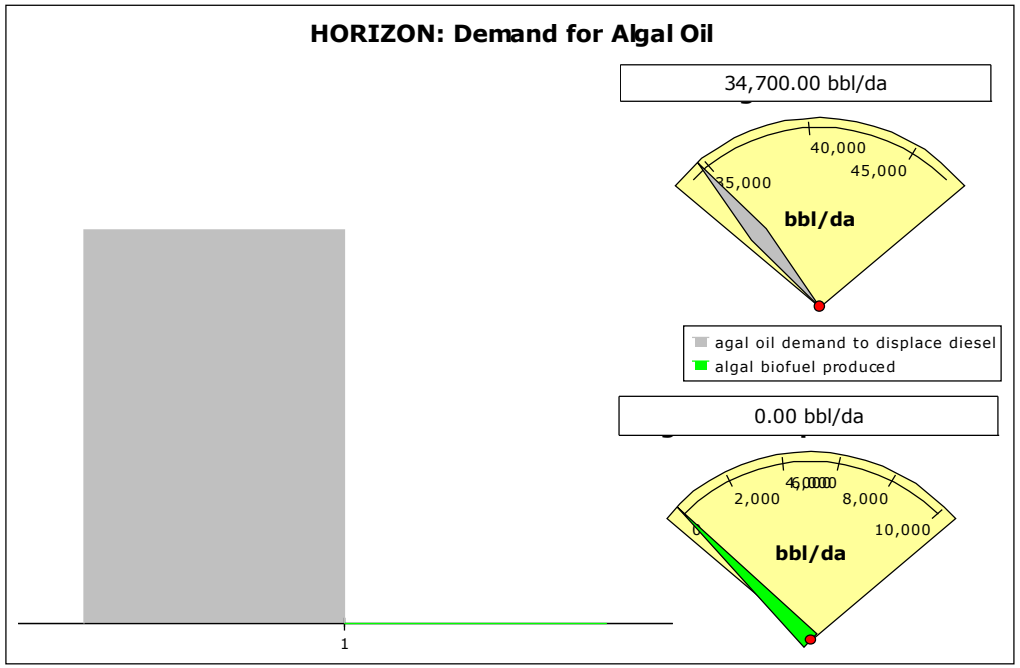
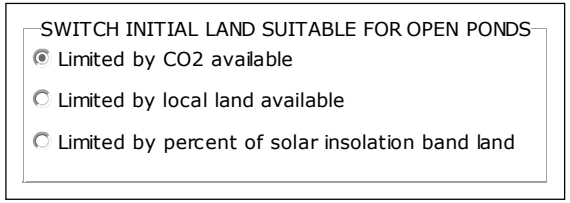
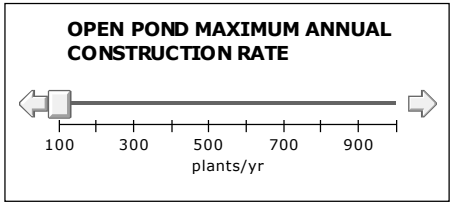
Prototype: Model interface

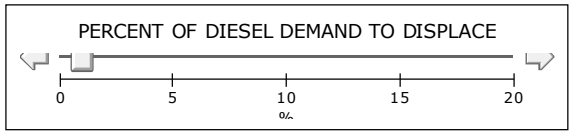


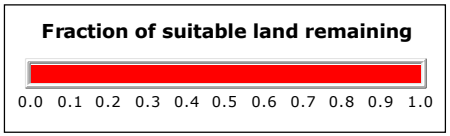
Yield	Sun hours
15.00 g/(da*m sq)	A < 2000
17.65 g/(da*m sq)	B 2000 - 2200
19.41 g/(da*m sq)	C 2201 - 2400
21.18 g/(da*m sq)	D 2401 - 2600
22.94 g/(da*m sq)	E 2601 - 2800
24.71 g/(da*m sq)	F 2810 - 3000
26.47 g/(da*m sq)	G 3001 - 3200
28.24 g/(da*m sq)	H 3201 - 3400
30.00 g/(da*m sq)	I > 3400











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Model demonstration: flight simulator metaphor

Conclusion

- This approach will not produce a single prediction, nor a point estimate
- This approach will produce a detailed understanding of the algal biomass/biofuel domain and projections of the future
- The understanding will come from:
  - Participation in model construction: data, process
  - Exercising the model
  - Running sensitivity tests

Everyone is welcome to help!

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The classic questions for us

- Not *'Is the model valid,'* but

- *Is the model suitable for its purposes and the problem it addresses?*
- *Is the model consistent with the slice of reality it tries to capture?*

(Richardson & Pugh 1981)

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