Biological Energy Institute

Clean Biofuels and Energy Independence

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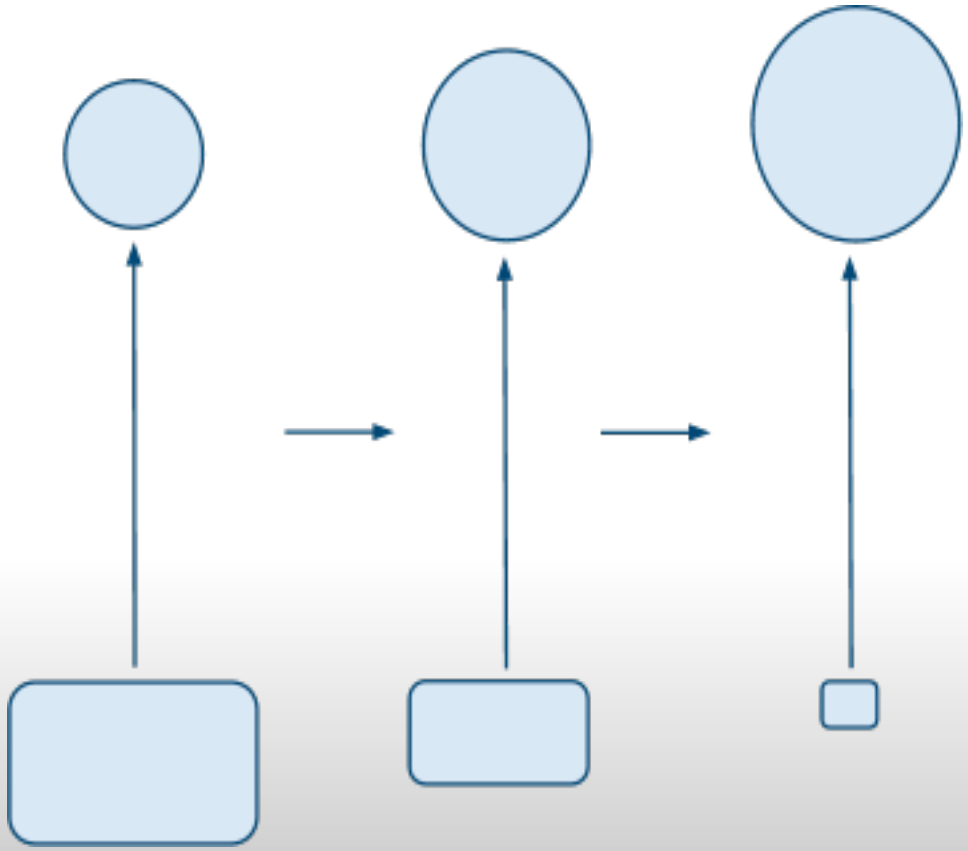
Energy of the Present: Unsustainable Pollution

- Peak Oil
- Global Warming
- Economic Depression
- Political Conflicts

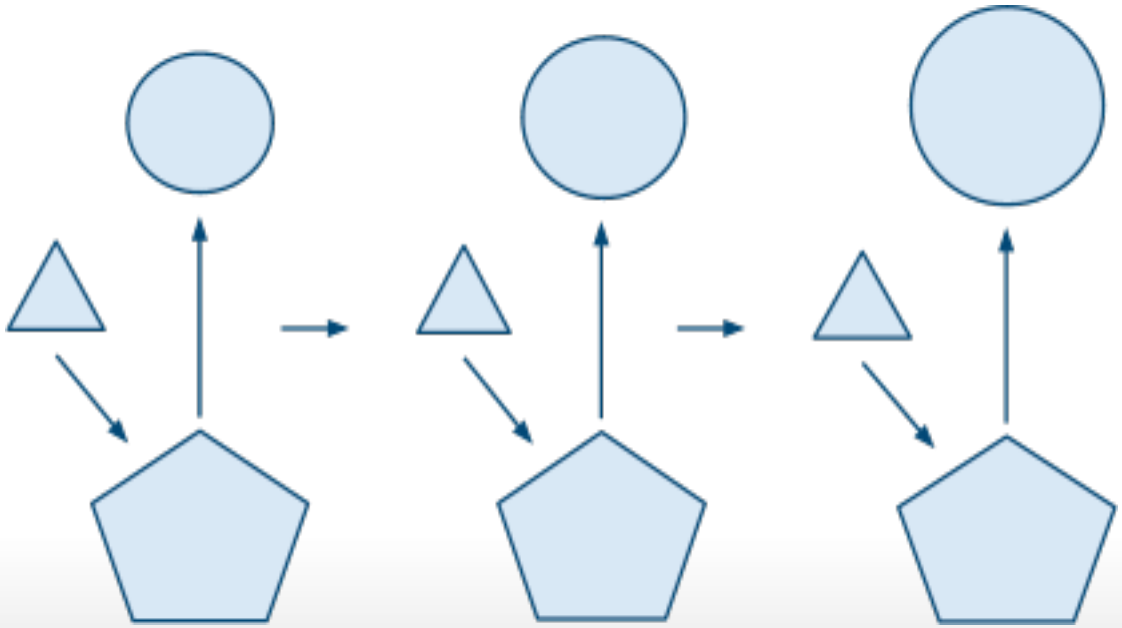
Oil versus Population Model



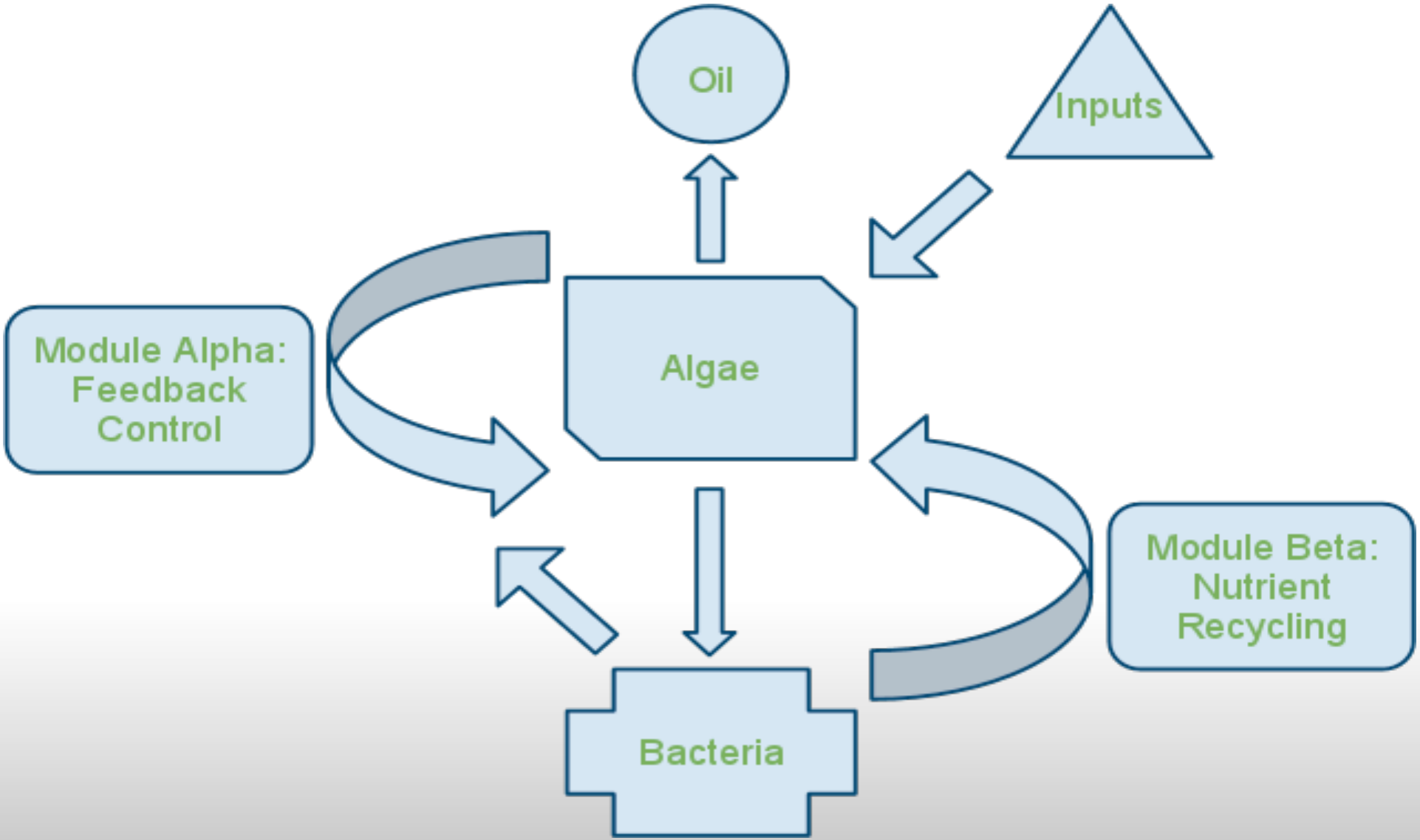
Energy of the Future:
The Self-Sustaining Fuel System

- Increased Supply
- Sustainable Growth
- Conflict Aversion
- Improved Understanding

Biofuel versus Population Model



SIVE (Self-Sustainable System for Sustainable Energy)
Device Diagram: Overview



Systems-Level Overview

- Population Control
  - Self-regulation
    - Stabilize system as a whole
  - Cross-regulation
    - Algae and Bacteria codependent as a safety mechanism
  - External Factors
    - Self-regulation: Dependent on nutrient levels
    - Algae: Sunlight, ammonia, dissolved CO_2
    - Bacteria: Dead algae, dissolved O_2
- Nutrient Recycling

SIVE Device Diagram: A Closer Look

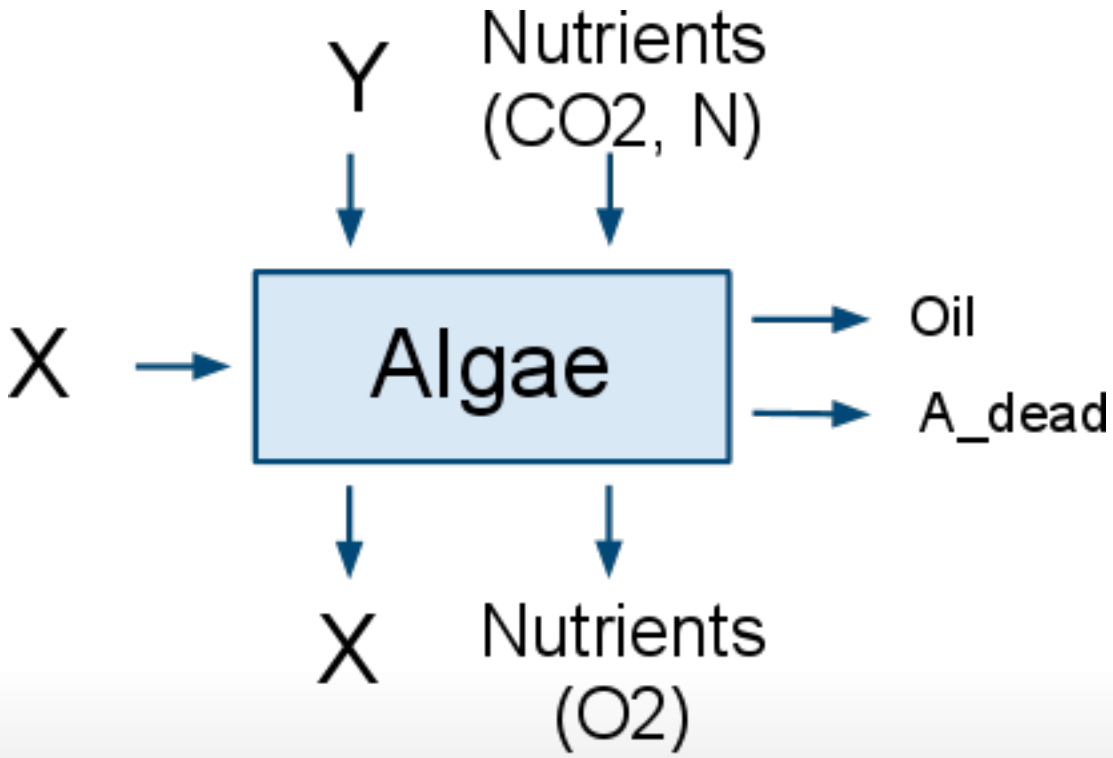
Organism Choices

- Algae
  - Modified B. Braunii
- Decomposer Bacteria
  - Why?
  - Putrefactors
  - Nitrosomonas
  - Nitrobacter

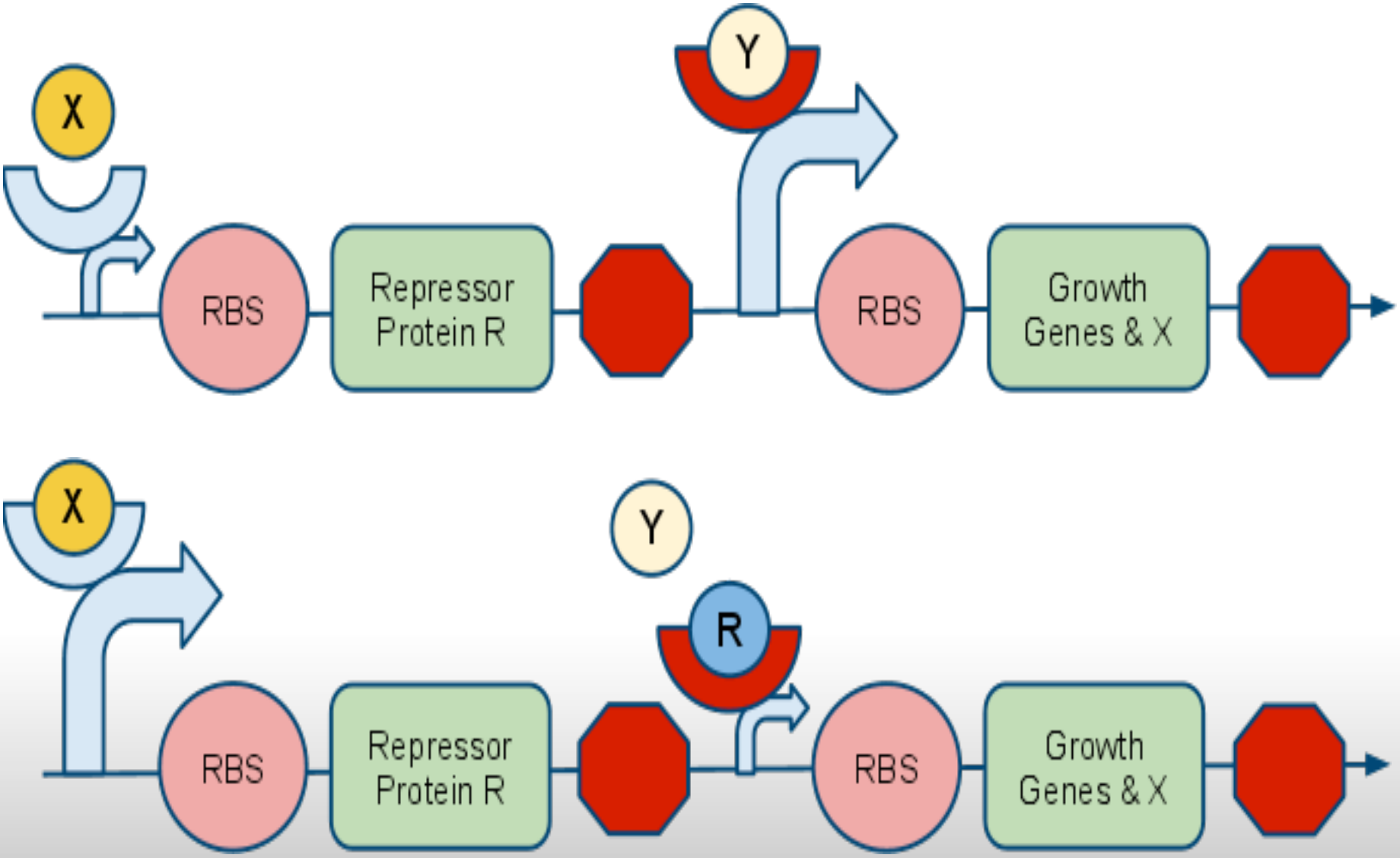
Container Choices

- Closed Photobioreactor
  - Experimental Design
  - Smaller, Cheaper, Controllable

SIVE Module Alpha: Feedback Control Overview



SIVE Module Alpha: Feedback Control Transcription



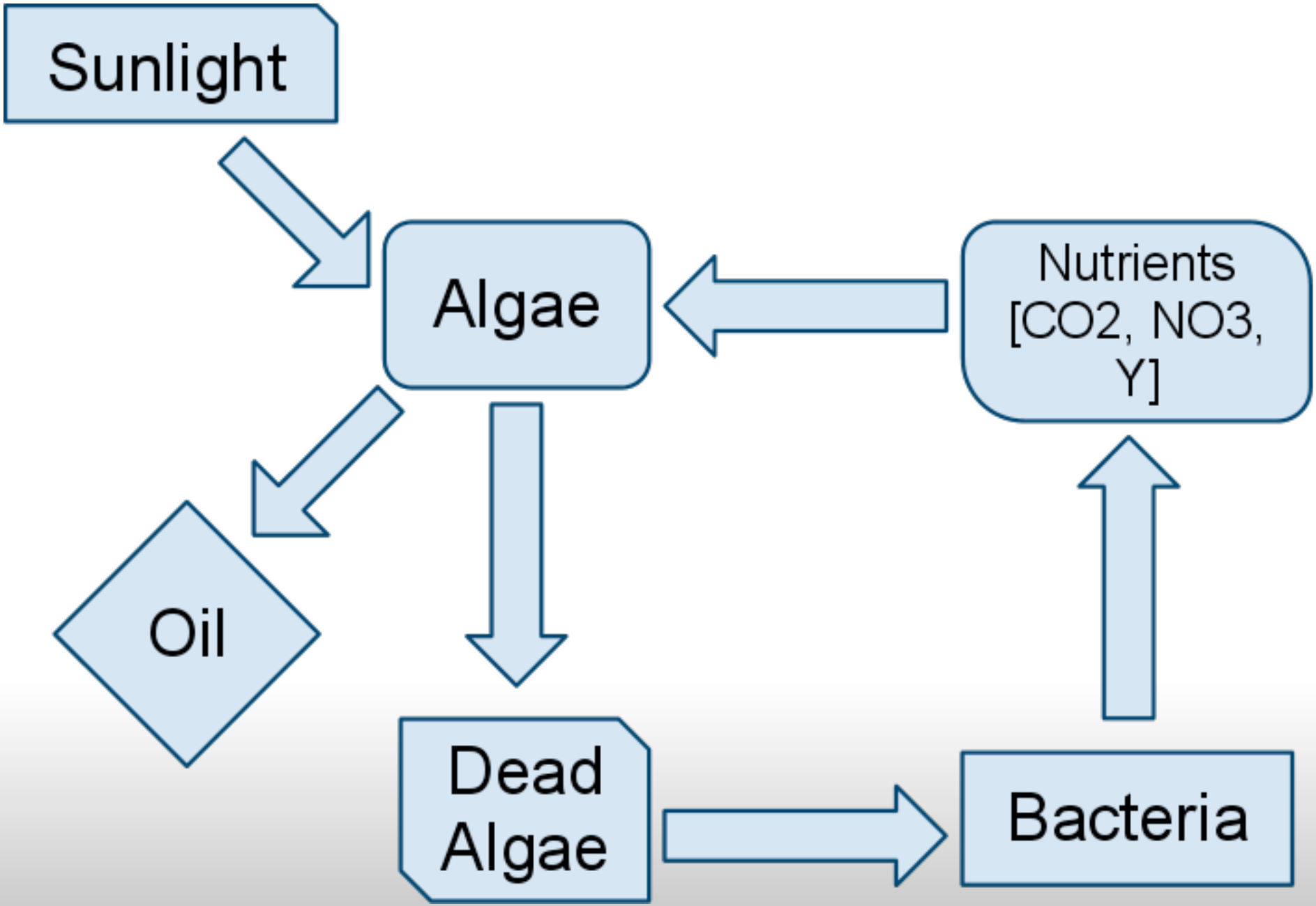
SIVE Module Alpha: Parts Specification

System Part	Description	Annotation
Repressor Promoter	Allows for transcription of R.	Constitutively weak; strongly induced by X.
X Promoter	Allows for transcription of X.	Constitutively weak; strongly induced by Y, but repressed by R.
Terminator	Halts transcription of mRNA.	Necessary for inverter function.
Repressor Gene	Produces Repressor R protein.	Inhibits algae growth and X production, serving to decrease population levels; binds much better than Y to X Promoter.
X Gene	Produces X; likely accompanied by growth proteins.	Encourages algae growth; serves to temporarily increase population levels.
Y Protein	Allows for improved transcription of X Gene.	Produced by system bacteria; required for algae to produce X and survive.
Ribosome Binding Site (RBS)	Allows for translation of subsequent proteins.	Necessary for protein production.
External Factors	Likely Sunlight, Carbon Dioxide, and Water.	Establish an upper limit on algal growth, and therefore on bacterial growth.

SIVE Module Alpha Summary

- Method: Self-Regulation via Quorum Sensing
  - Basal X Expression
  - Inducer/Inverter Combination
- Motivation: Maximum Sustainable Fuel Output
  - Sustainability through Stability
  - Organism Escape Failsafe

SIVE Module Beta: Nutrient Recycling



SIVE Module Beta: Parts Specification

System Part	Description	Annotation
Algae	Bioreactor workhorse. Decomposes into dead algae.	Produces oil.
Bacteria	Bioreactor facilitator. Regenerates system nutrients.	Produces nutrients from dead algae and oxygen.
Sunlight	Provides energy to the system.	Fluctuating input.
Dead Algae	Decomposing algae; eventual nutrient source.	Intermediate energy component.
Nutrient Stream	Produced from dead algae by bacteria.	Consists of CO2, NO3, and Y protein.
Oil	Produced by living algae.	Overall system product.

SIVE: Testing and Debugging

- Self-Regulation Systems
  - Algae: Vary X levels, measure [algae]
    - Via signal, e.g. GFP and fluorescence levels
  - Bacteria: No self-regulation
- External Regulation Systems
  - Co-Regulation
    - Algae: Vary Y levels, measure [alg]
    - Bacteria: Vary X levels, measure [bac]
    - Test Alg and Bac together (w/o self-reg)
  - Nutrients
    - Alg and Bac: check that will grow indefinitely so long as nutrients sufficient
    - Ideally, sunlight: proportionally change alg rate constants

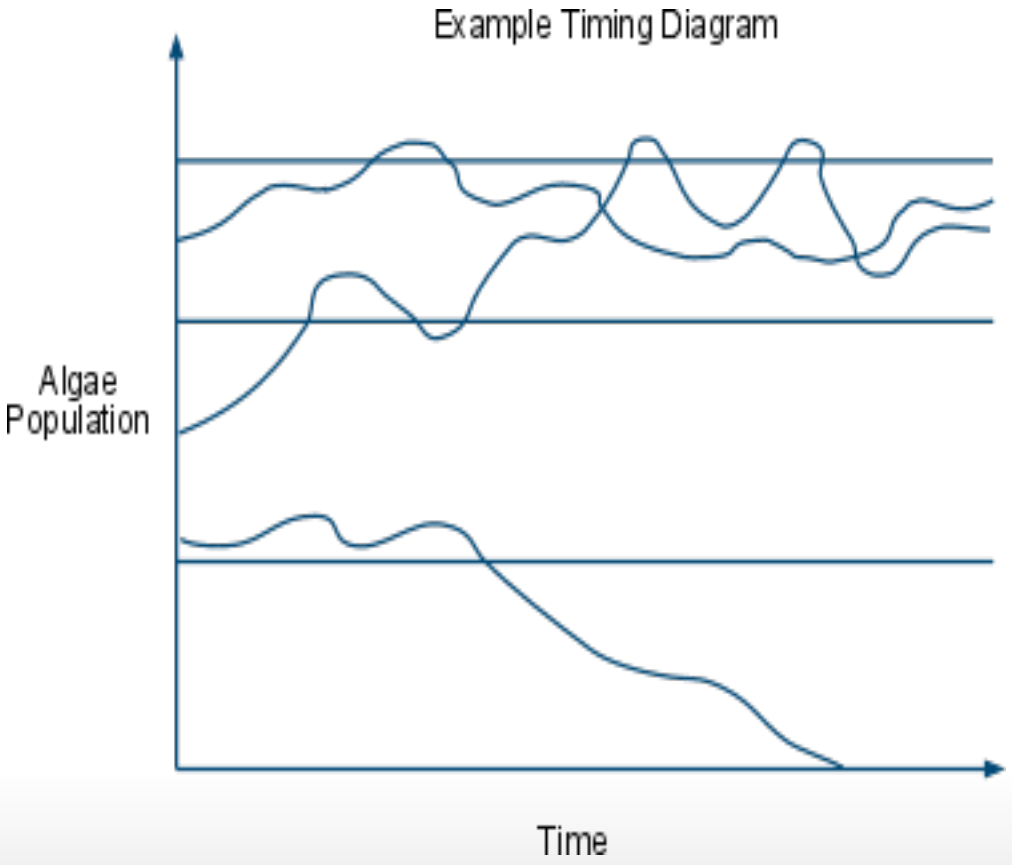
SIVE Modelling Equations

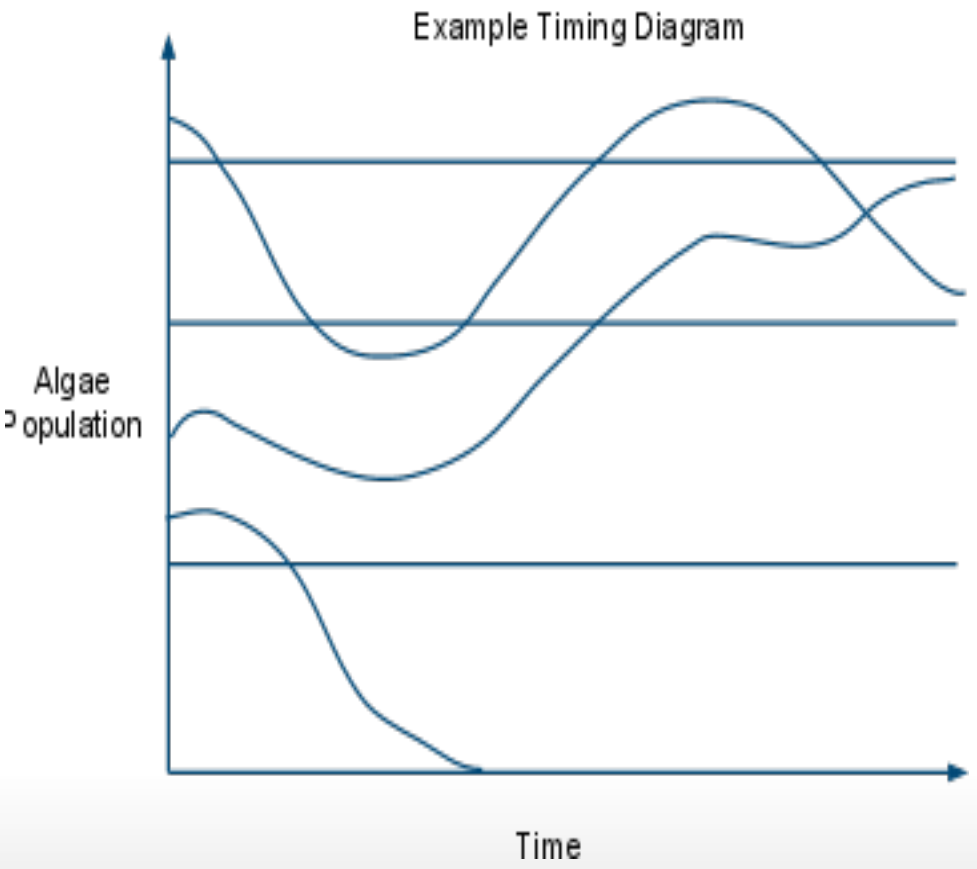
- -> CO_2
- A + NO_3 + CO_2 + Sunlight + Y -> A + A + Sunlight + Y + O_2 + CO_2 (if have constant CO_2 input)
- B + O_2 + A_dead -> B + B + CO_2(negligible) + NH_4
- B2 + NH_4 -> B2 + NO_2
- B3 + NO_2 -> B3 + NO_3
- A -> A + Oil
- B, B2, X, Y -> 0
- A -> A_dead
- Sunlight: probably want to cycle on off very rapidly (sin function)
- Initial inputs: Alg, Bac, NO_3
- Constant Inputs: Sunlight, CO_2?, misc. nutrients
- Assume well-mixed, no lag due to diffusion

SIVE Modelling Equations: Thresholds

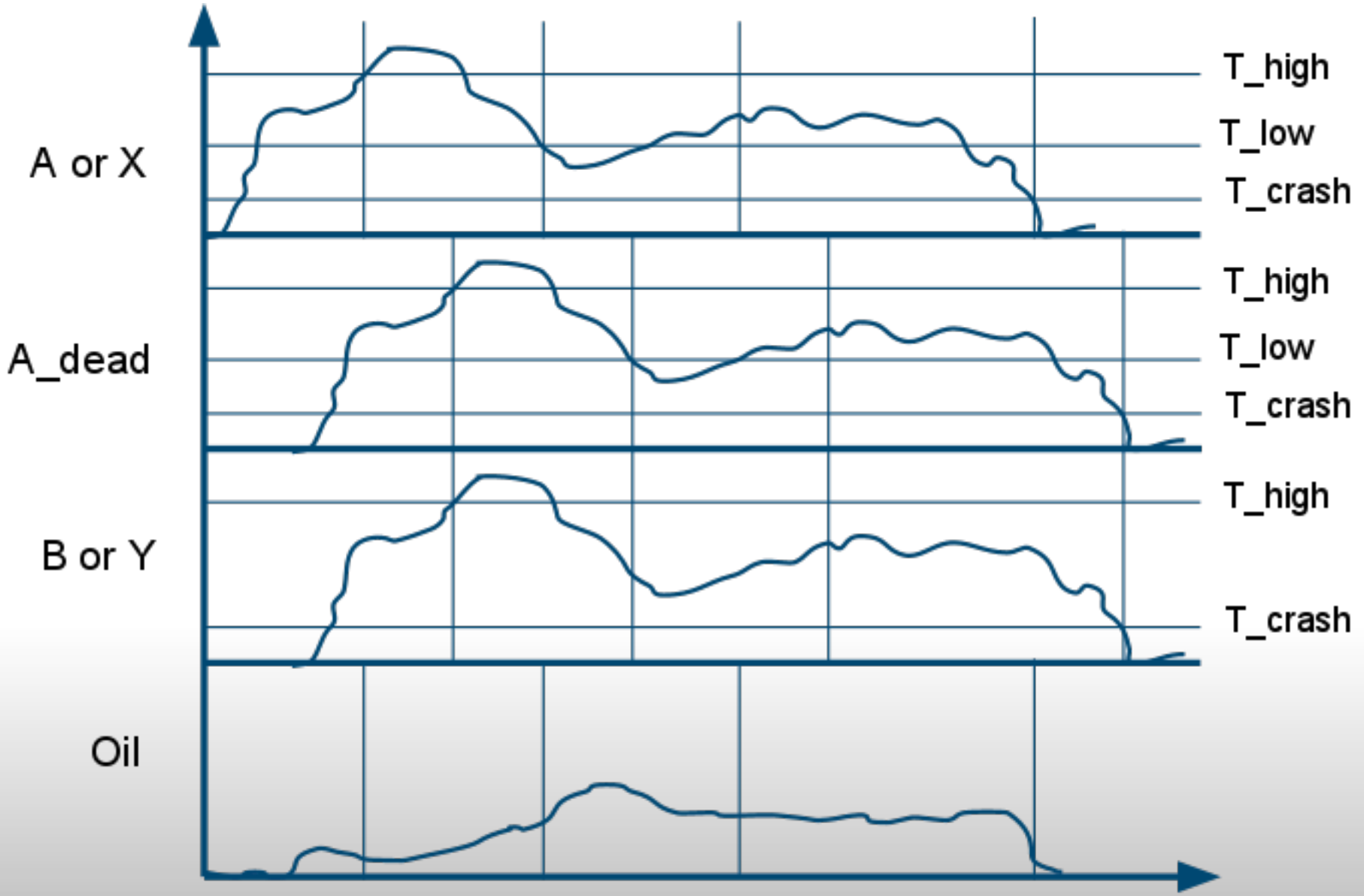
If X > T_high:
    do not run A -> A + A
If X < T_low:
    do not run A -> oil + A
If X < T_crash:
    A = 0
If Y > k_high * X
    do not run B -> B + B
If Y > k_crash * X
    B = 0

SIVE Timing Diagram: Theoretical Optimum





SIVE Timing Diagram
Relationships between A, B, A_dead, oil



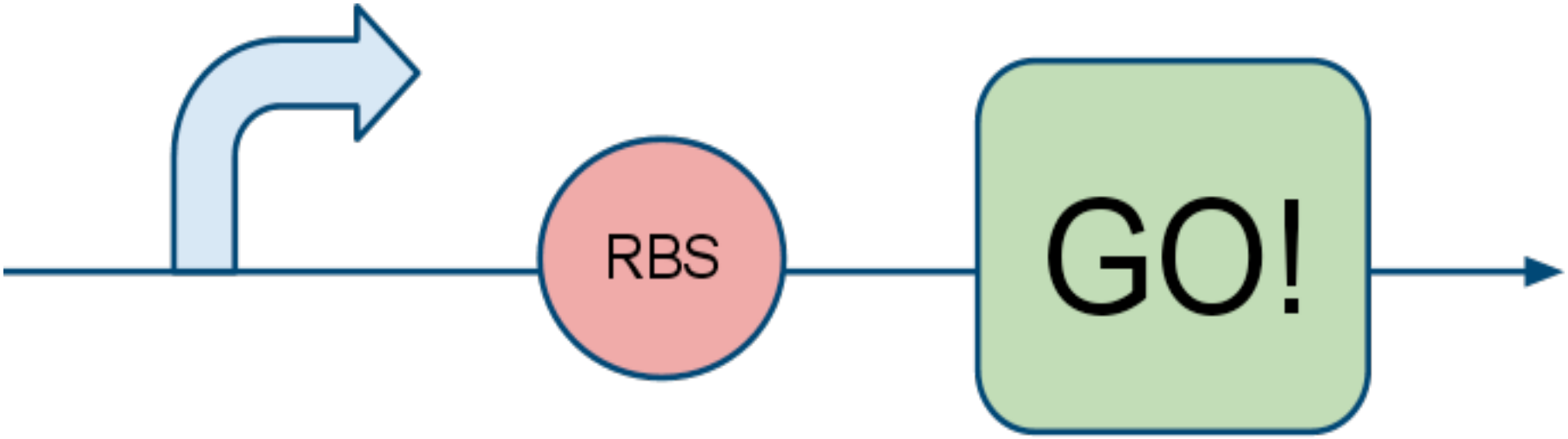
Open Issues with SIVE

- Photobioreactor Design
  - Efficiency through Flow Loops (Light & Mixing)
  - Comparison with Static System
  - Issues of Algae/Bacteria Coexistence
- Additional Modules
  - Antibiotic Expression
  - Algae Protection / Flexibility
- Steady-State Rate Constants

Beyond Energy: SIVE Population Control in Biological Engineering

- Population Control in Biological Engineering
- Applications to Medicine & Bioremediation
- Foundational Experimental Tool

Decision



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Bacteria versus Natural Decomposition

"A high presence of oxygen around algae cells is undesirable. The combination of intense sunlight and high oxygen concentration results in photooxidative damage to algal cells.

Because of the constraint on the concentration of dissolved oxygen, tube length is limited in horizontal tubular reactors. This restriction makes it very difficult for tubular reactors to be scaled-up."

http://pubs.acs.org/doi/full/10.1021/ie901459u

These closed loop systems require many supplements to be added to provide nutrients for algae growth.

http://www.freepatentsonline.com/y2010/0055765.html