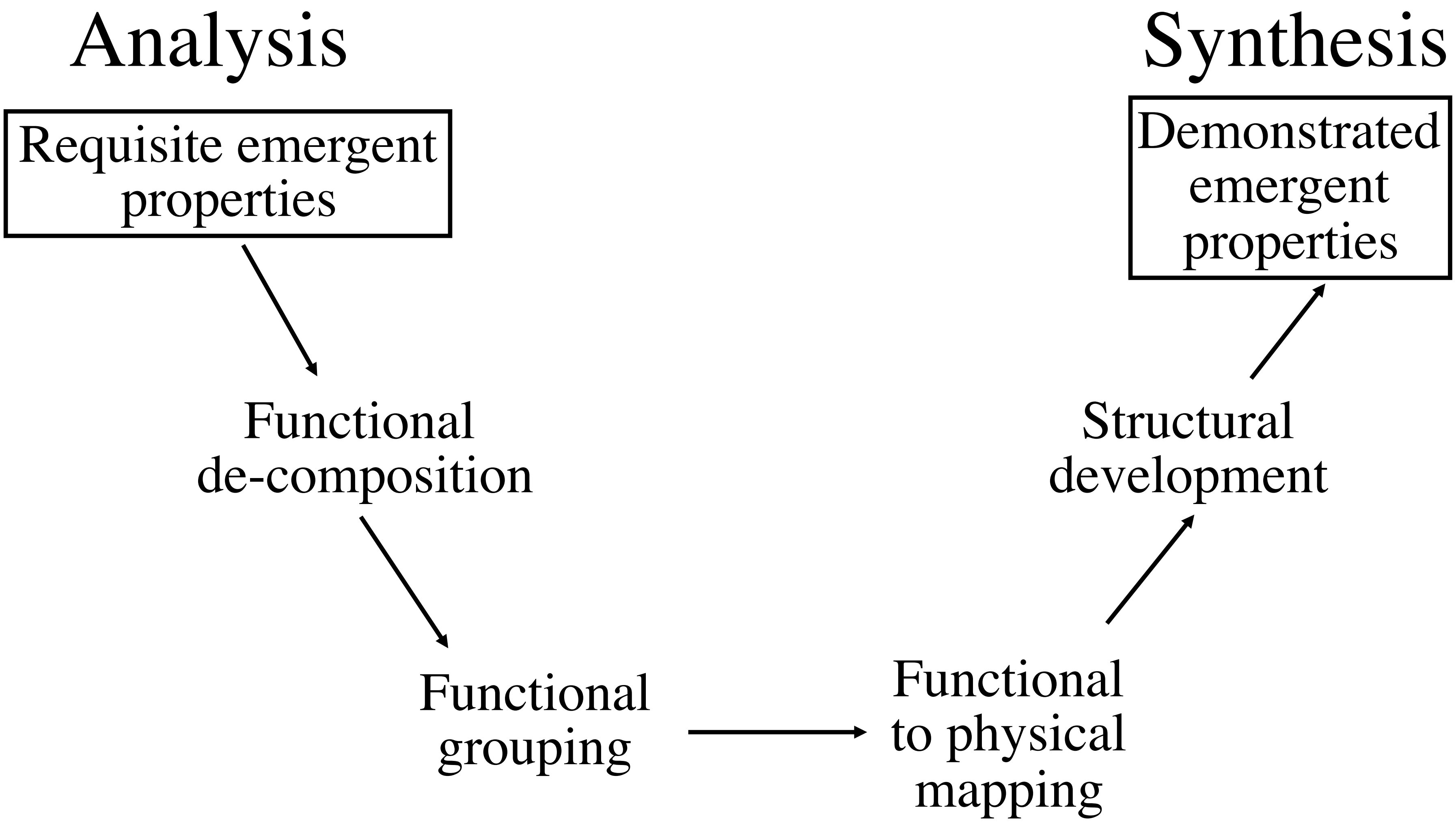
New Systems Engineering Design for the New Millenium

So, what's wrong with the Classic Approach?

Classic Systems Engineering—the Process



Classic Systems Engineering

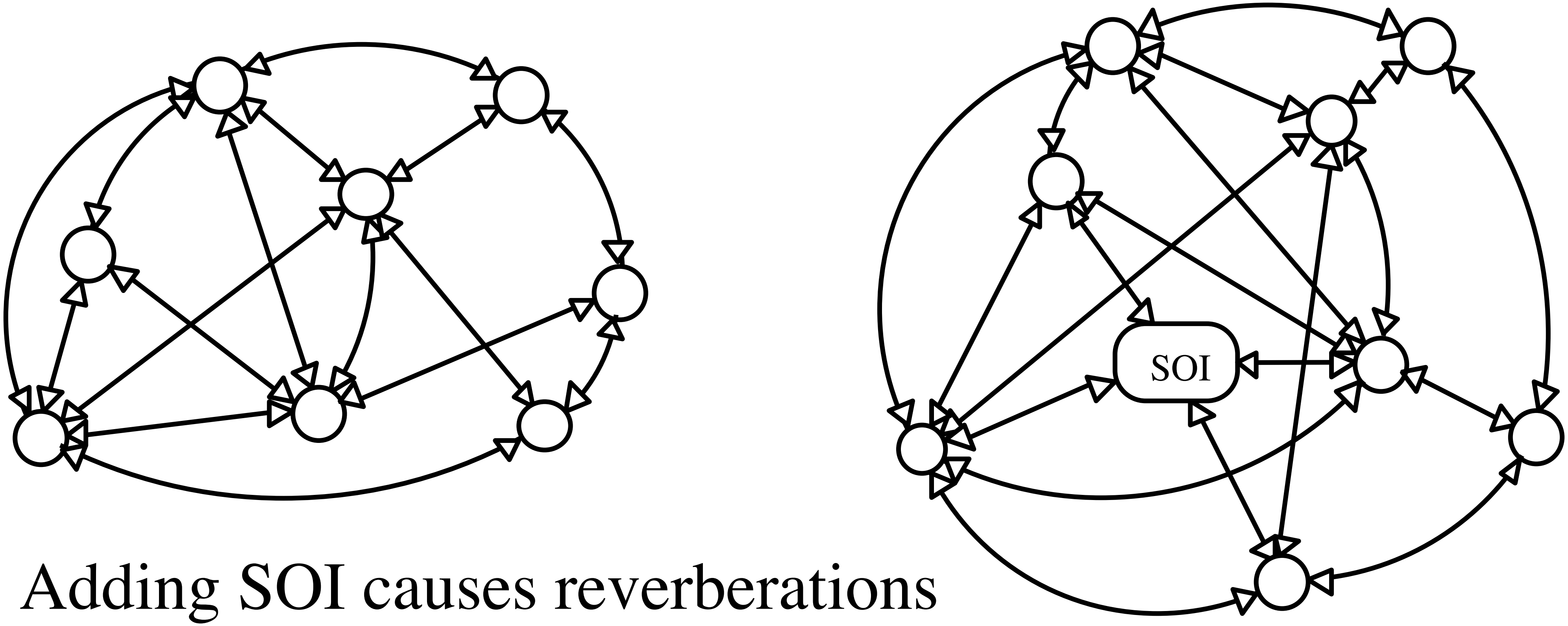
- Remarkable successes e.g. Neil Armstrong on the Moon
- Spectacular failures, too e.g. HUBBLE, many Information Systems
  - Some failures due to non-observance of basic principles
  - Many failures due to counter-reaction of existing systems when a new system is introduced
- We expend great energy on designing and building the "inside" of a system, but very little on exploring what will happen when that system goes into use…
  - Will it work with other systems in their joint environment
  - …or will the other systems/environment reconfigure/react?
  - Will it self-sustain, adapt, evolve in service over 10/20/40/100 years?

Principle of System Reactions

- *When a set of interacting systems is in equilibrium and either a new system is introduced to the set, or one of the existing members or interactions is perturbed then, insofar as they are able, the other members will re-arrange themselves so as to oppose the set*

After Le Chatelier

Principle of Systems Reactions



- Adding SOI causes reverberations
- New configuration stability may be static, dynamic, catastrophic, chaotic…how would you know?
- Makes writing requirements of limited value!

So, how can we "do it better"?

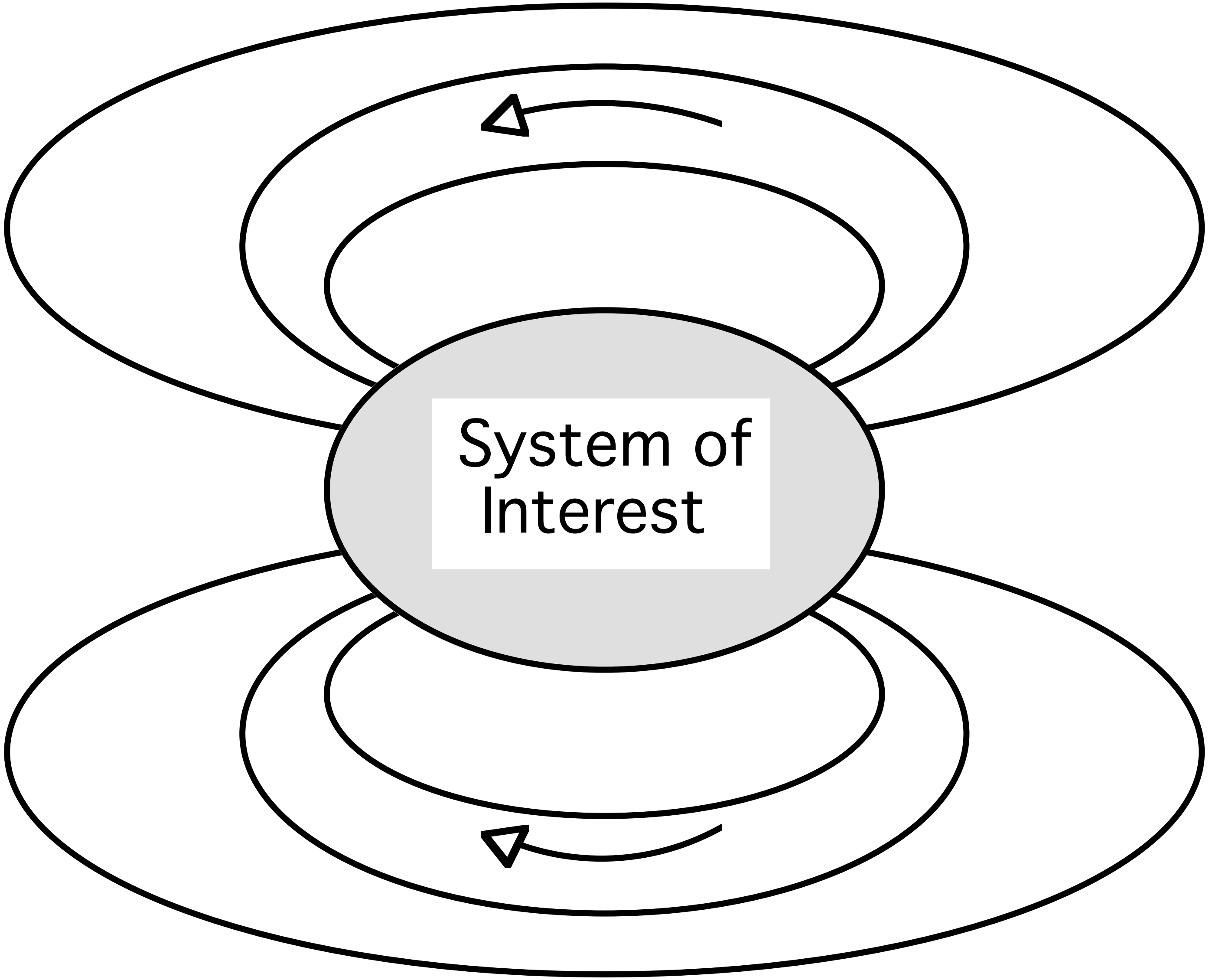
NSE—Basic Concepts

- Look outwards *first!*
- Explore impact of new system on other systems
  - Operational effects in an operational environment
    - Will it be effective? How will other systems react?
  - Resource effects in a resource environment
    - Will it self-sustain?
    - Will it drain other systems? How will they react?
- Synthesize (i.e. build up) new system to create continuous, closed process loops
  - from inflow through to outflow…
  - through external environment and back to inflow
    - If need be, create new/complementary systems to close the loop!

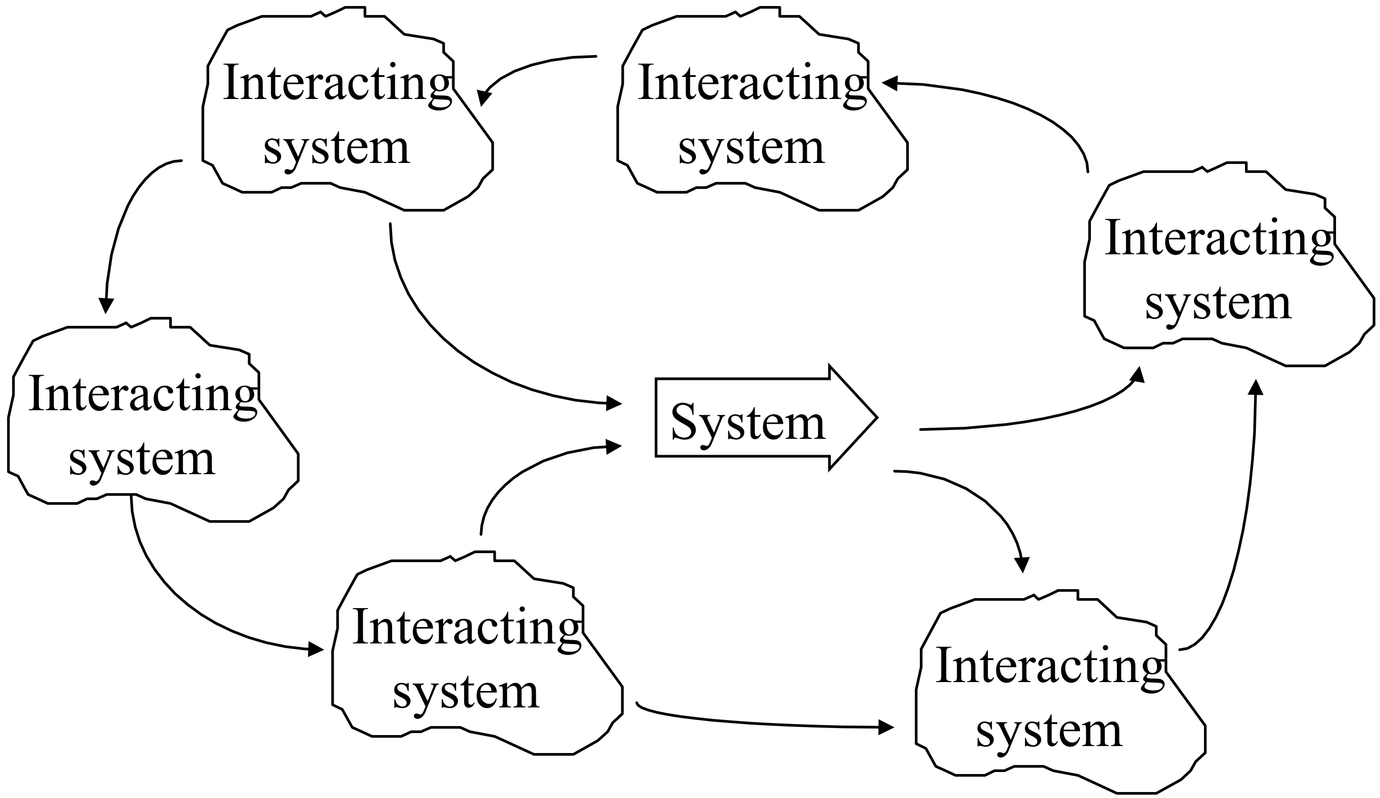
Purpose?

- To establish new systems in a harmonious, co-operative, sustaining environment
- Without this,
  - They will need to adapt after delivery, or
  - They will not endure, and
  - They can never be optimal

Sustaining Closed Loops



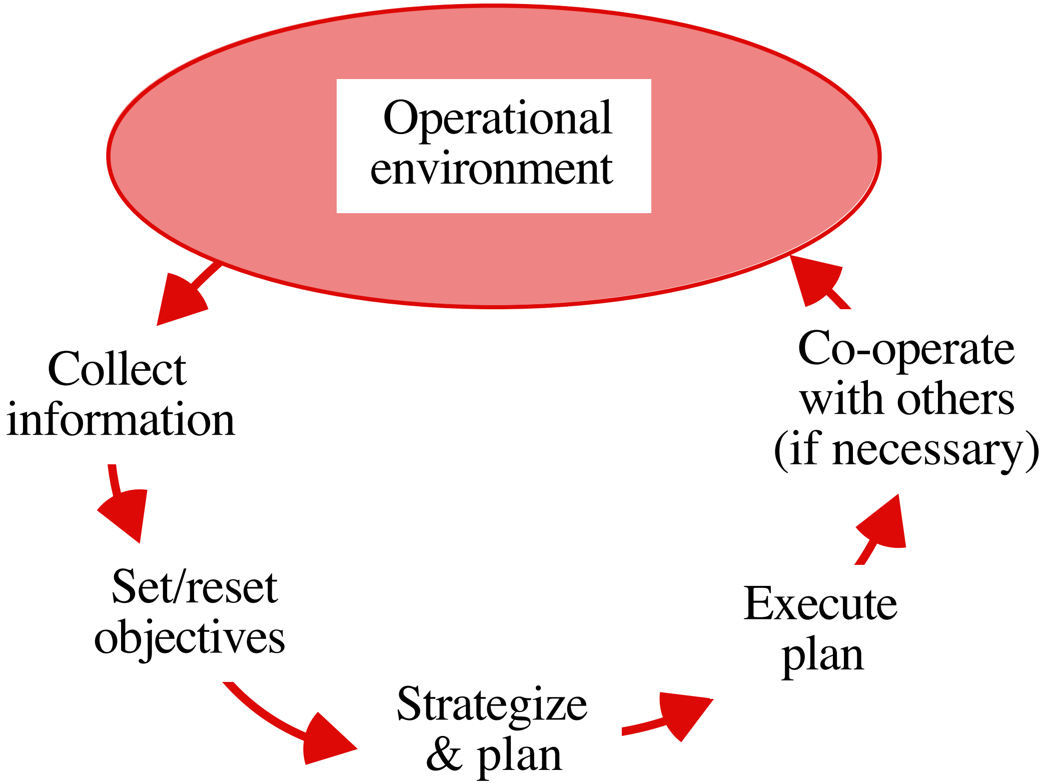
Thinking in Loops



- System's outflows inevitably interact with other systems in environment to affect own inputs. Introducing new system into existing set disturbs them. Subsequent dynamics may militate against or for sustaining new system
- Thinking in loops encourages: completeness of sets of interactions; identification of multiple systems "relaxation condition"—likely eventual state of set

Guided by:— Generic Reference Model…

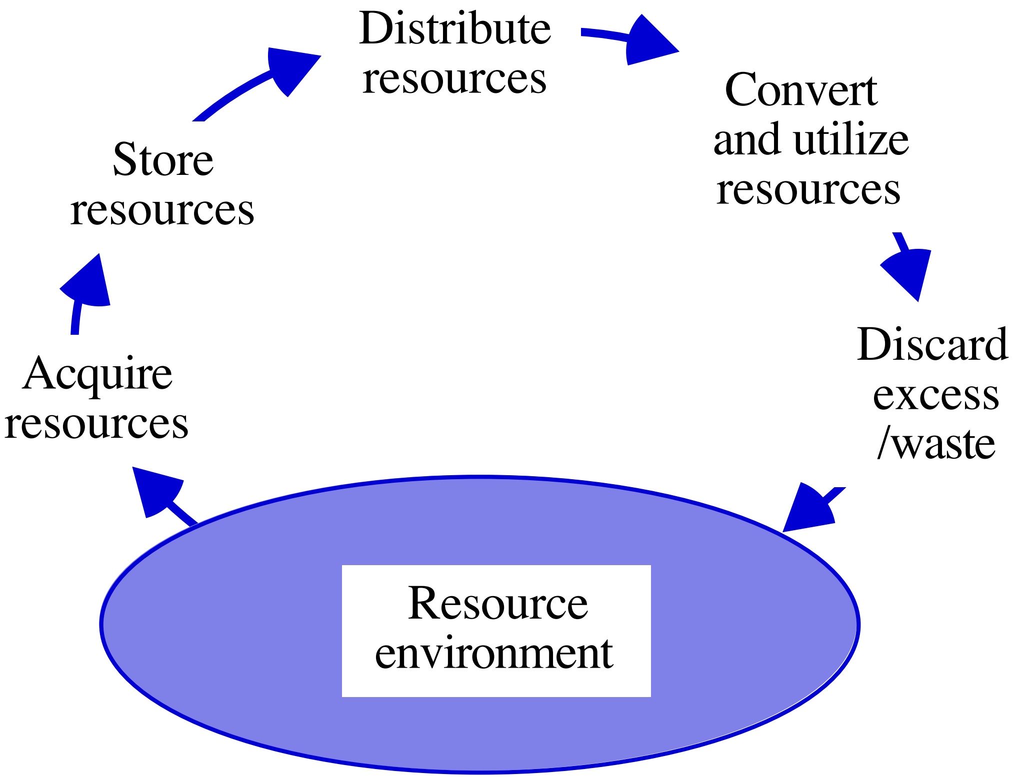
Mission Management



- N.B. work is done in processing information into a plan—energy required to "drive" loop
- Internal "push/pull force" maintains loop dynamics

- Essentially, Mission Management can do no more than:—
  - collect information from the operational environment,
  - set/reset objectives based in part on that information,
  - strategize and plan how to achieve those objectives,
  - execute the resultant plan and
  - co-operate with others in the operational environment if need be.

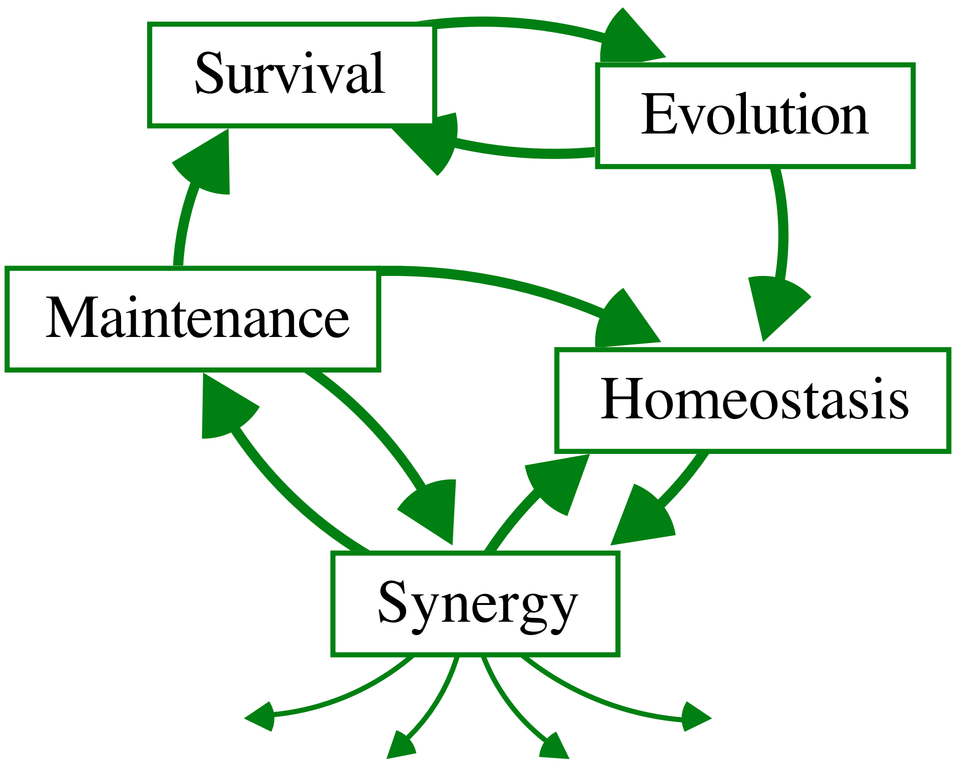
Resource Management



- N.B. Resource management absorbs resources
- Storage essential to meet continual internal demand
- Internal “push/pull force” maintains loop dynamics

- Essentially, all that Resource Management does is:—
  - Acquire resources from some external environment
  - store them
  - distribute them internally
  - convert them to the locally-required form
  - utilize the converted resource
  - discard excess or waste

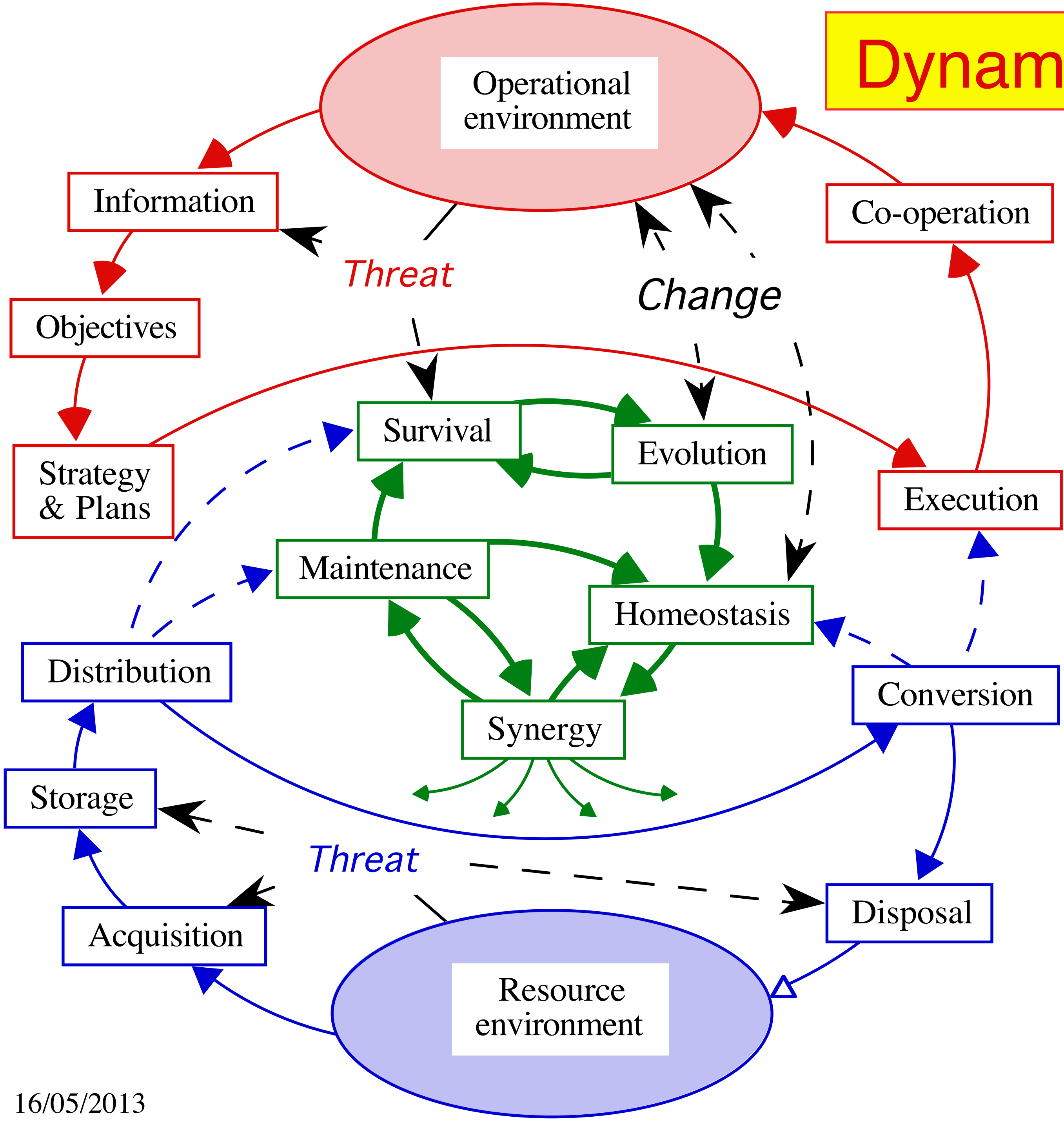
Viability Management



- Elements of Viability not mutually independent, e.g. survival essential for evolution, evolution improves survivability
- Synergy—co-operation between the parts to achieve some desired external effect

- Generally "capable of living"—in this context, able to exist devoid of mission or purpose, c.f. neonate
  - Internal parts are synergistic
  - Internal environment is regulated (homeostasis)
  - Able to evolve and adapt to changing environment
  - Able to detect, locate and replace faulty parts
  - Able to Survive attack from "outside"

Dynamic GR(Function)M



- 3 elements seen in respective “environments”
- Viability provides platform for Mission Management
- Resources provide energy & materials for Viability and (internal) operations
- Threats to Mission Management, Resource Management
- Change challenges Homeostasis (resist) and Evolution (adapt)

So, we have a set of Concepts Do we need Anything Else?

Very Much so…

To understand how systems interact

What makes them stable?

Viability Model states what *should* be, but…

How are systems designed to *be* viable, efficient, effective, etc?

Value of Unified Systems Theory

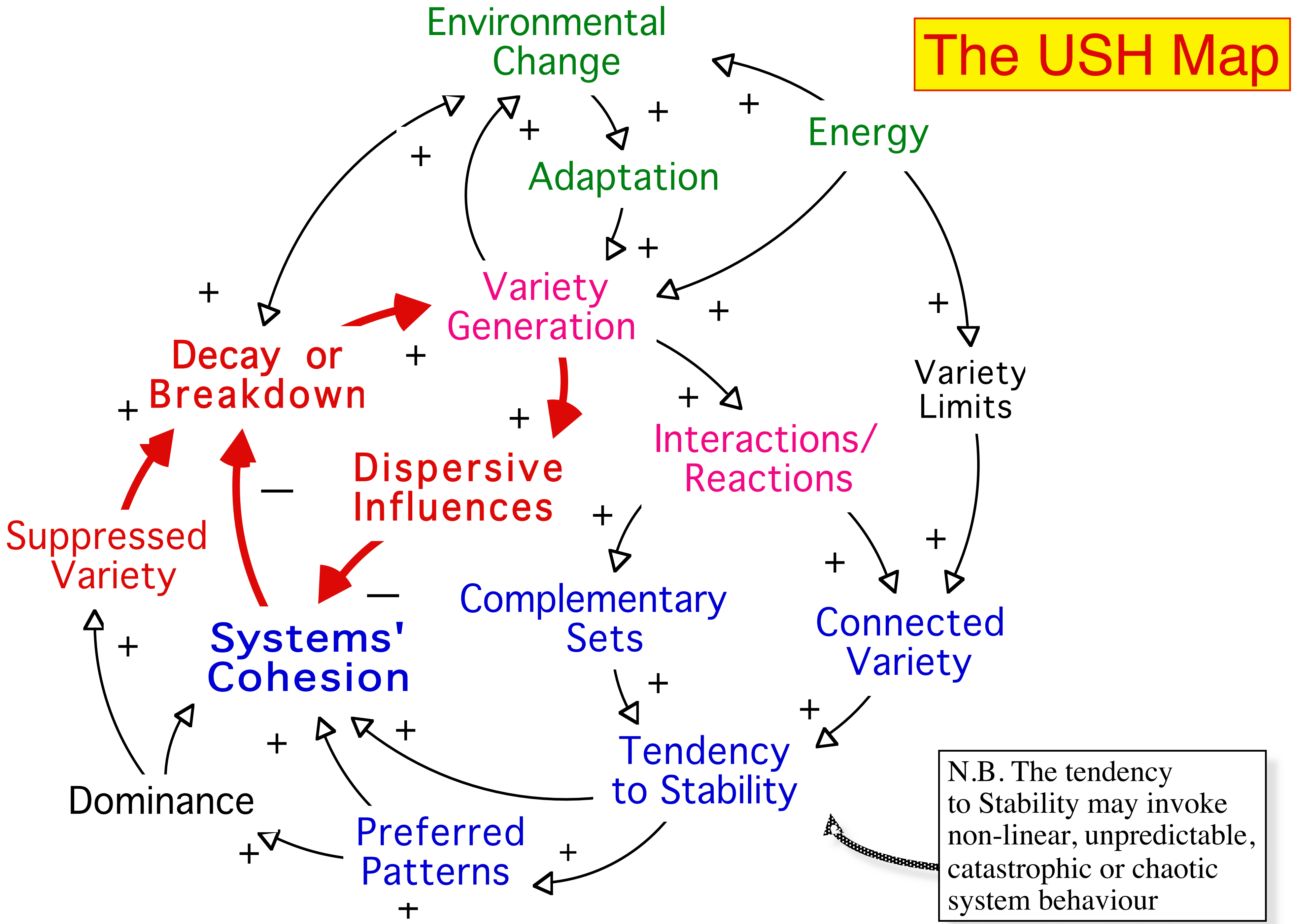
- Applies to all systems—technological, social, political…
- Establishes bases for stability, adaptability, longevity, collapse…
- Creates a set of guidelines for the synthesis of new, robust and effective systems

The USH Principles as a Set

- The *Principle of Reactions* address their tendency to equilibrium
- The *Principle of Cohesion* addresses the internal / external balance of an interacting system and hence the basis for its form and its survival
- The *Principle of Connected Variety* addresses the bases of stability between interacting systems
- The *Principle of Limited Variety* identifies limits to variety and hence to Connected Variety and complexity
- The *Principle of Preferred Patterns* addresses the emergence of dominance through regeneration
- The *Principle of Adaptation* addresses the essential ability to change in response to Environment
- The *Principle of Cyclic Progression* examines life cycle, the generation of variety, stability, dominance and collapse or decay.

The USH Principles as a Set

- Together, they describe the lifecycle of any system
  - Its formation, development, maturation and demise
  - The causes of stability and longevity
  - The causes of demise and sudden collapse
- So, they show how to:
  - Make a system stable/bring a system down
  - Make a system endure for longer
  - Make a system more adaptable in the face of changing environment


The USH Map
Environmental Change
Energy
Adaptation
Variety Generation
Decay or Breakdown
Variety Limits
Interactions/ Reactions
Dispersive Influences
Suppressed Variety
Systems' Cohesion
Complementary Sets
Connected Variety
Tendency to Stability
Dominance
Preferred Patterns
N.B. The tendency to Stability may invoke non-linear, unpredictable, catastrophic or chaotic system behaviour

USH Synthesis Guidelines

- Connected variety encourages stability
  - Inadequate connectivity or variety = non-adaptability
  - Maintain/refresh variety to maintain stability
- Complementary variety reduces system entropy
  - Hence reduces internal energy = inefficiency
  - …and increases "work output"
- Linear process flow and interchange also reduce system entropy, with same benefits
- Dominance encourages cohesion, unless it also suppresses variety
- There are many forms of stability

New Systems Engineering

The Seven-Step Process

New Systems Engineering

- Based on theory—the Unified Systems Hypothesis
- A quite different approach to system design:
  - adds additional synthesis phase at beginning, to give "synthesis… analysis…synthesis"
  - does not use functional de-composition
    - employs Generic Reference Models instead, to synthesis system internal management and structure
  - initial synthesis phase anticipates perturbations within the interacting systems set.
    - Introduces either features within the SOI, or complementary systems, to neutralize unfavourable perturbations
  - outward looking, not introspective as classic systems engineering can be
  - universally applicable—can be applied to any system, technological, socio-technical or organizational

New SE—Design Guidelines

Step 1 Establish SOI Goals, Objectives and Targets by reference to Containing System(s)

Step 2 Identify (Sibling) Systems and their interactions to be perturbed by the SOI

Step 3 Conceive Complementary Systems as new/ modified Siblings to neutralize unwanted perturbations, and to close operational/resource loops

New SE—Design Guidelines

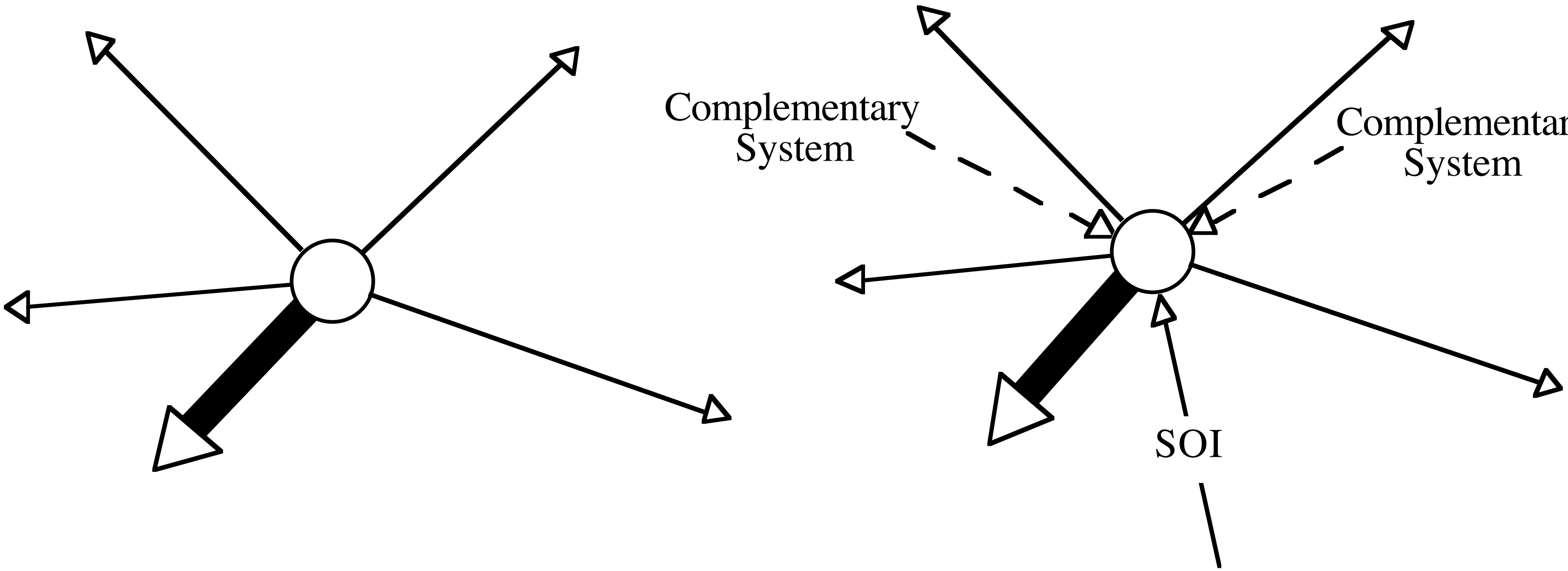
Step 4 Design SOI as an Open System to complement Sibling Systems in contributing to Containing System(s)' objectives

Step 5 Partition SOI, promoting internal connected variety, avoiding dominance

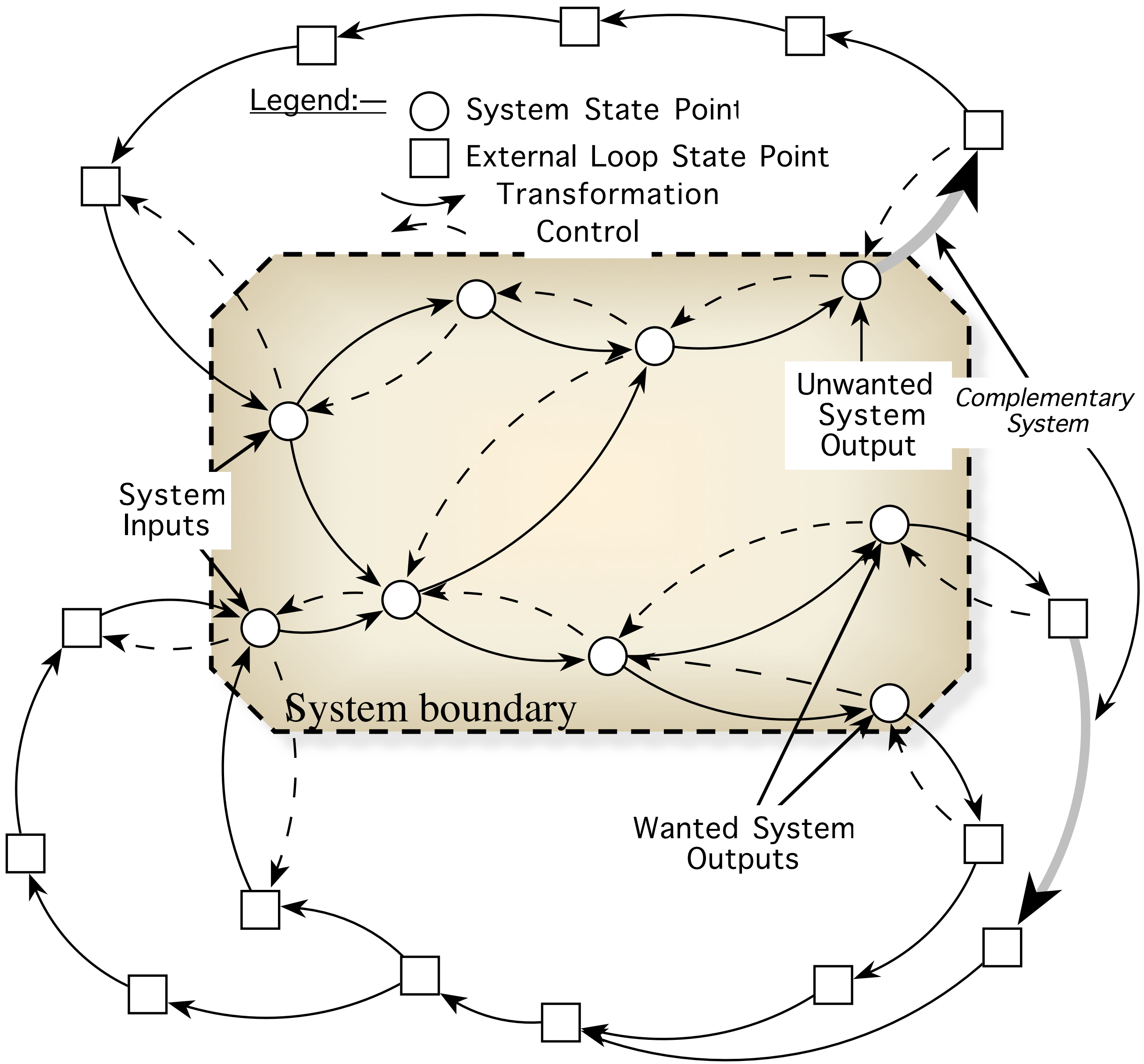
Step 6 Enhance SOI cohesives, diminish dispersives

Step 7 Interconnect that variety to promote Sibling stability, mutual self reward

Neutralizing Unwanted Perturbations

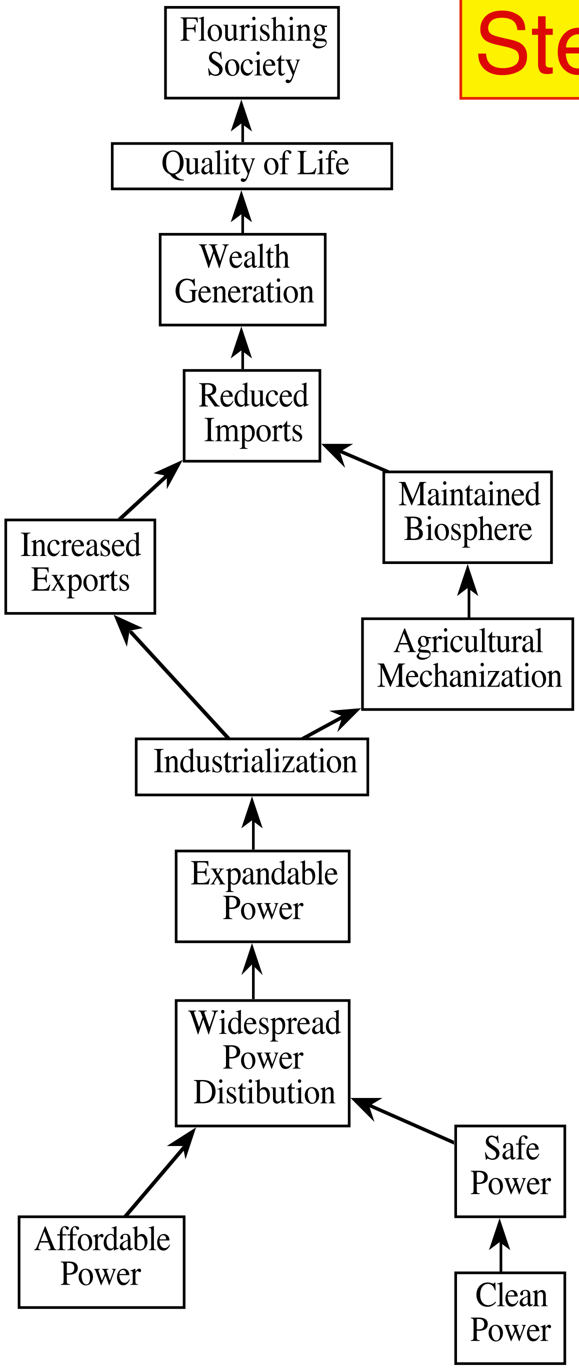


Open System Design Technique



Introductory Case Study

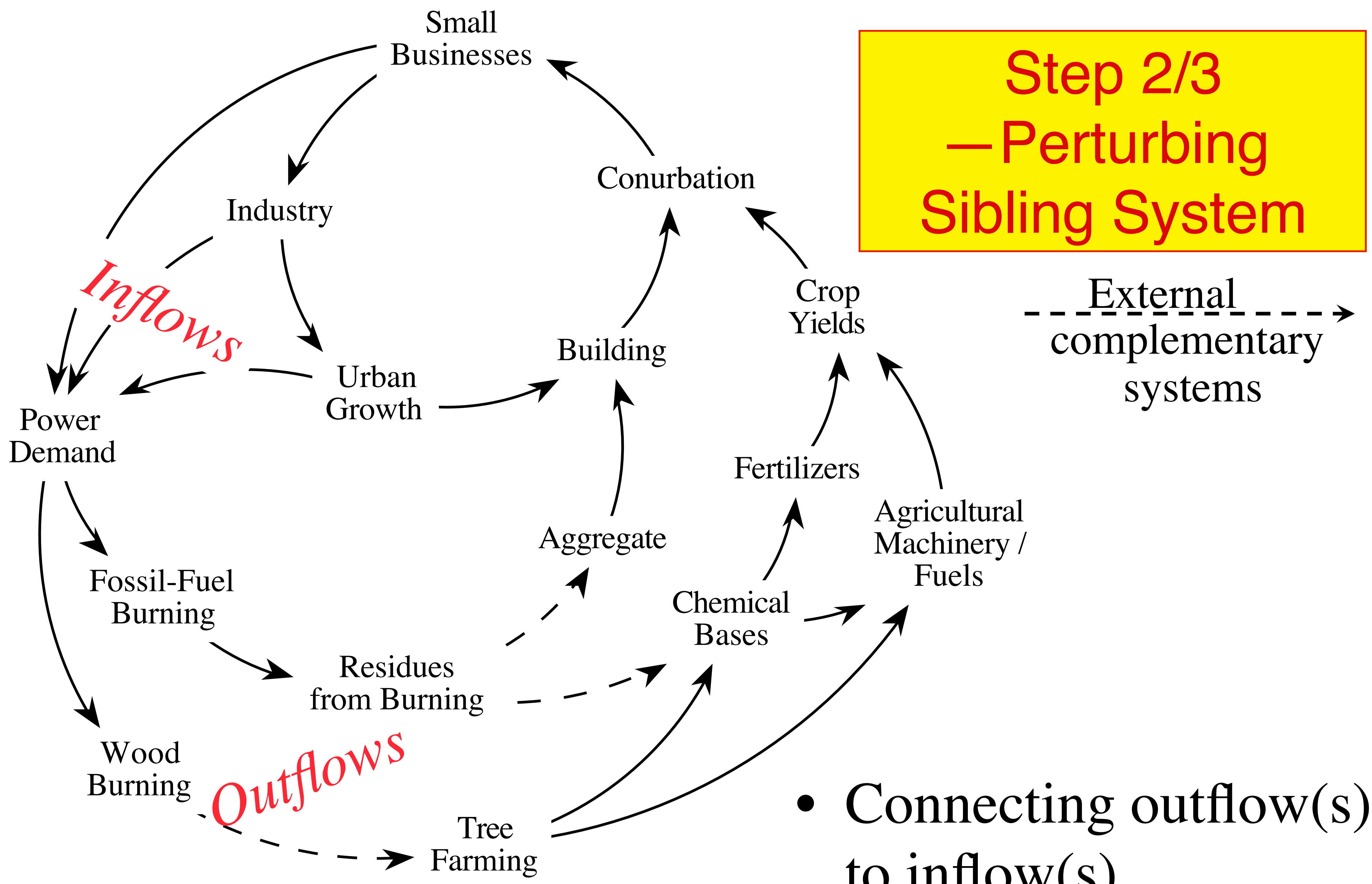
- A new, fossil-fuel power station is to be introduced to an under-developed region presently supporting a poor, largely agrarian society.
- Design a robust power system to contribute maximally to the region and to minimize any undesirable side-effects.



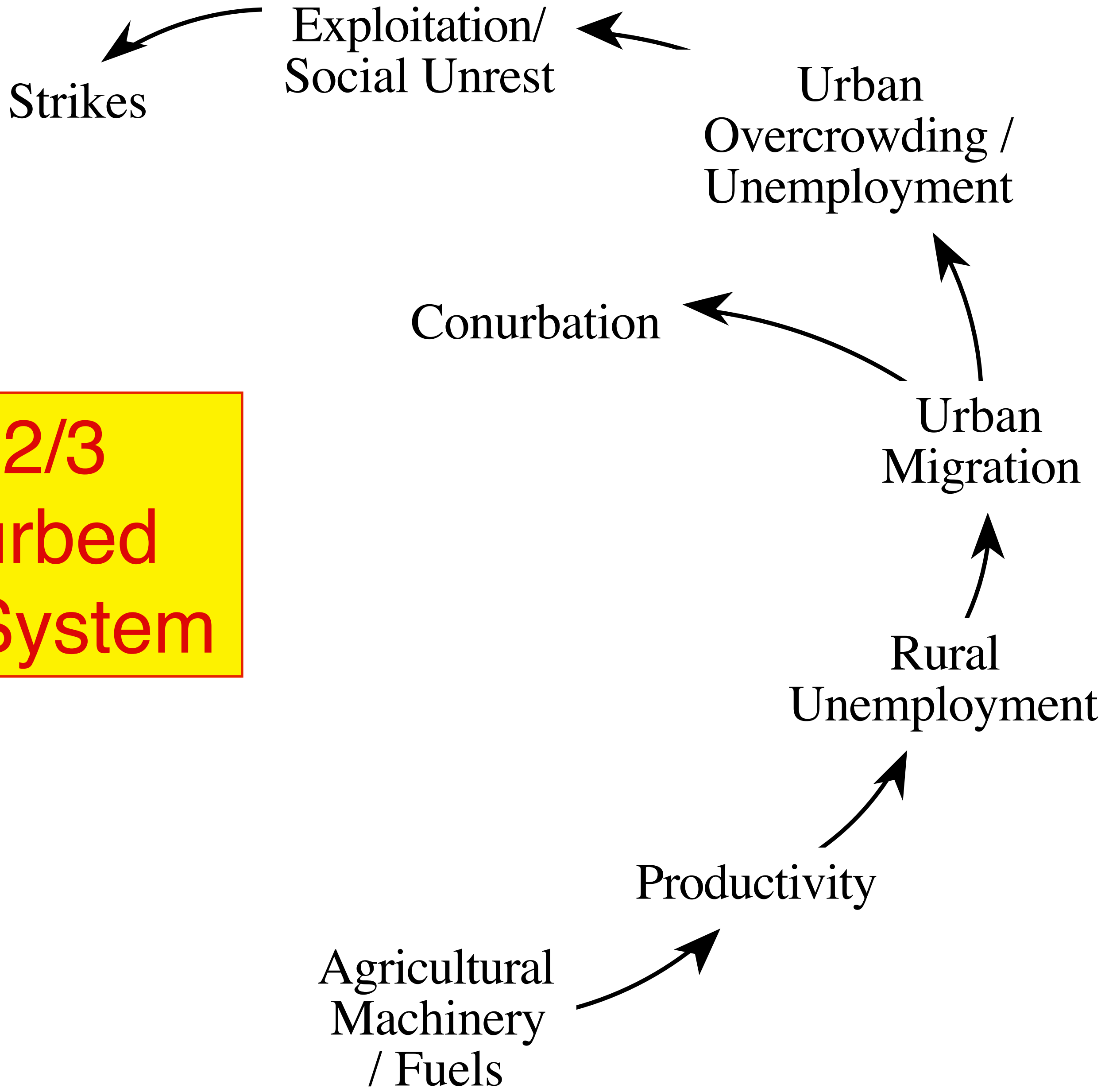
Step 1—Objectives

- To contribute to a Flourishing Society with an improved Quality of Life for all the citizens in the region through the provision of safe, clean, affordable electrical power.

Step 2/3 —Perturbing Sibling System



- Connecting outflow(s) to inflow(s)



Step 2/3 —Perturbed Sibling System

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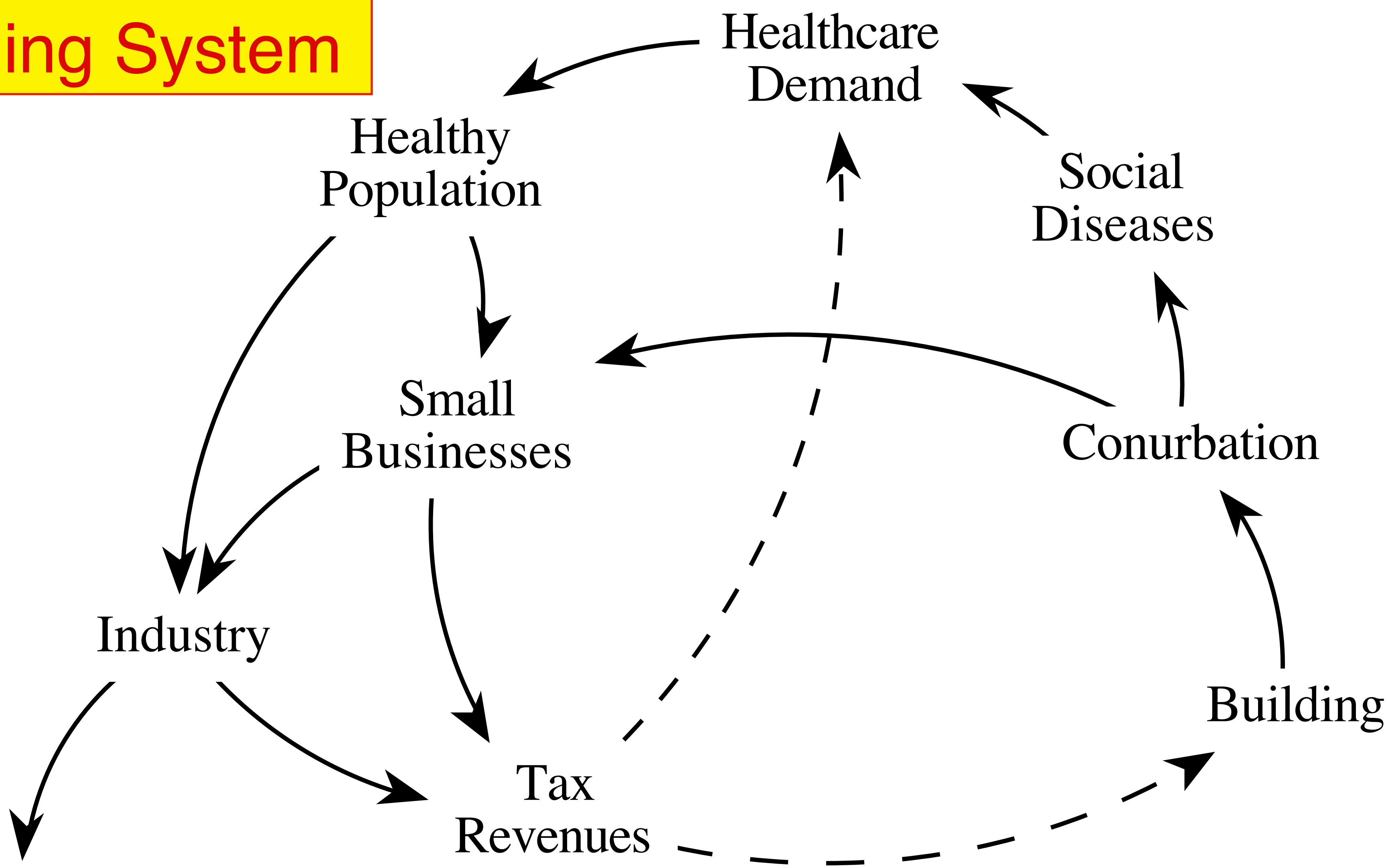
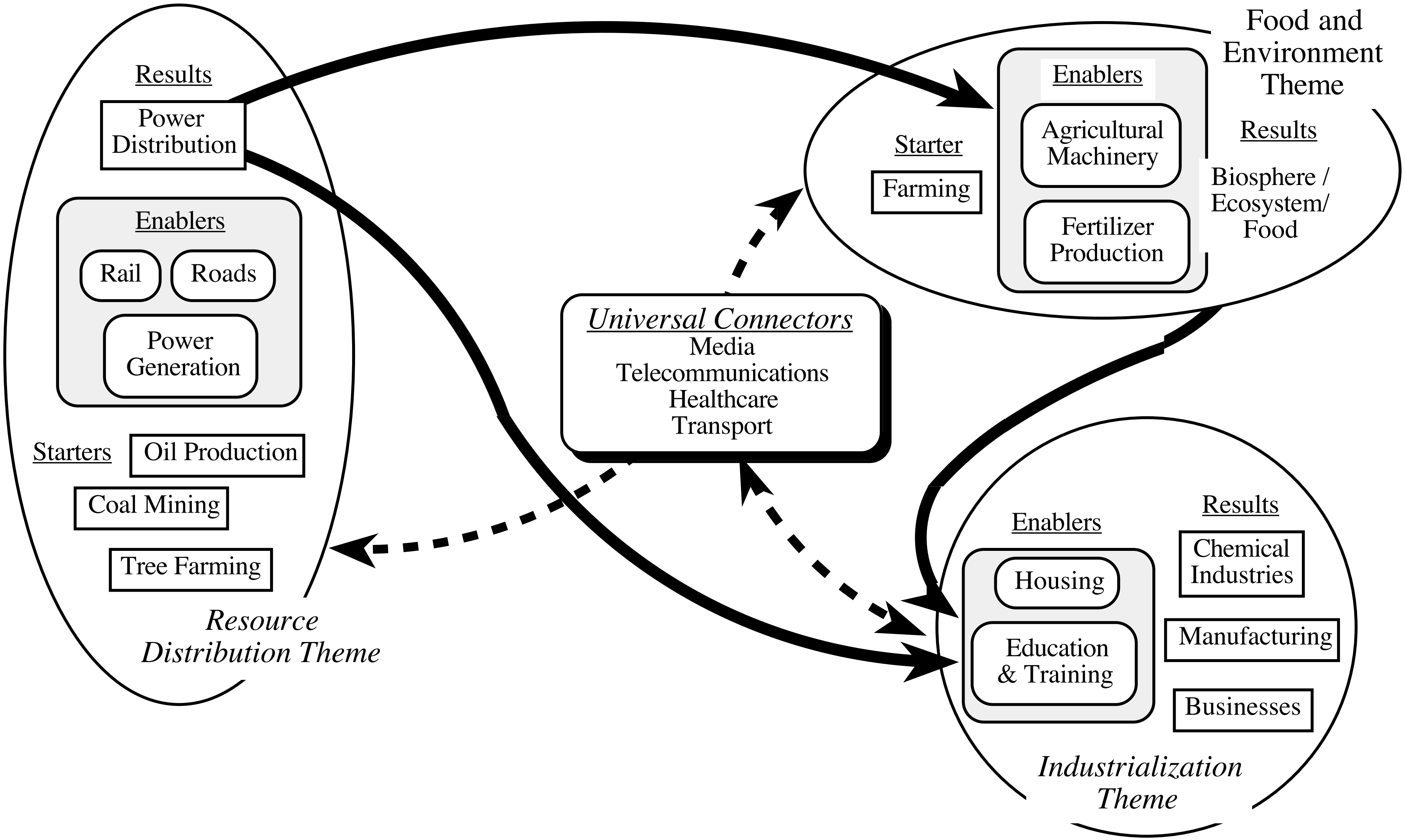
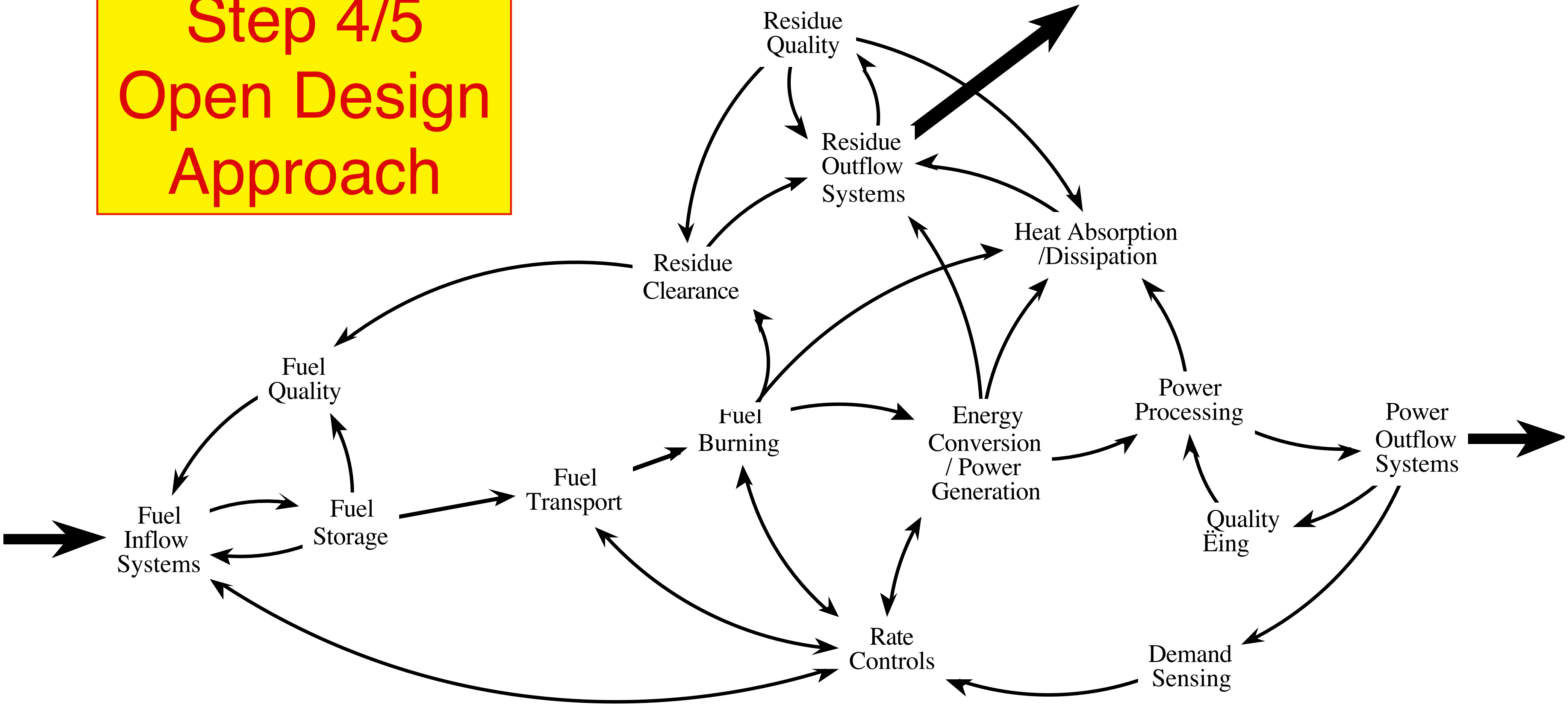


Step 3—An Enabling View



Step 4/5
Open Design
Approach



- Continuous movement from inflow(s) to outflow(s)
- Continuous feedback to regulate flows

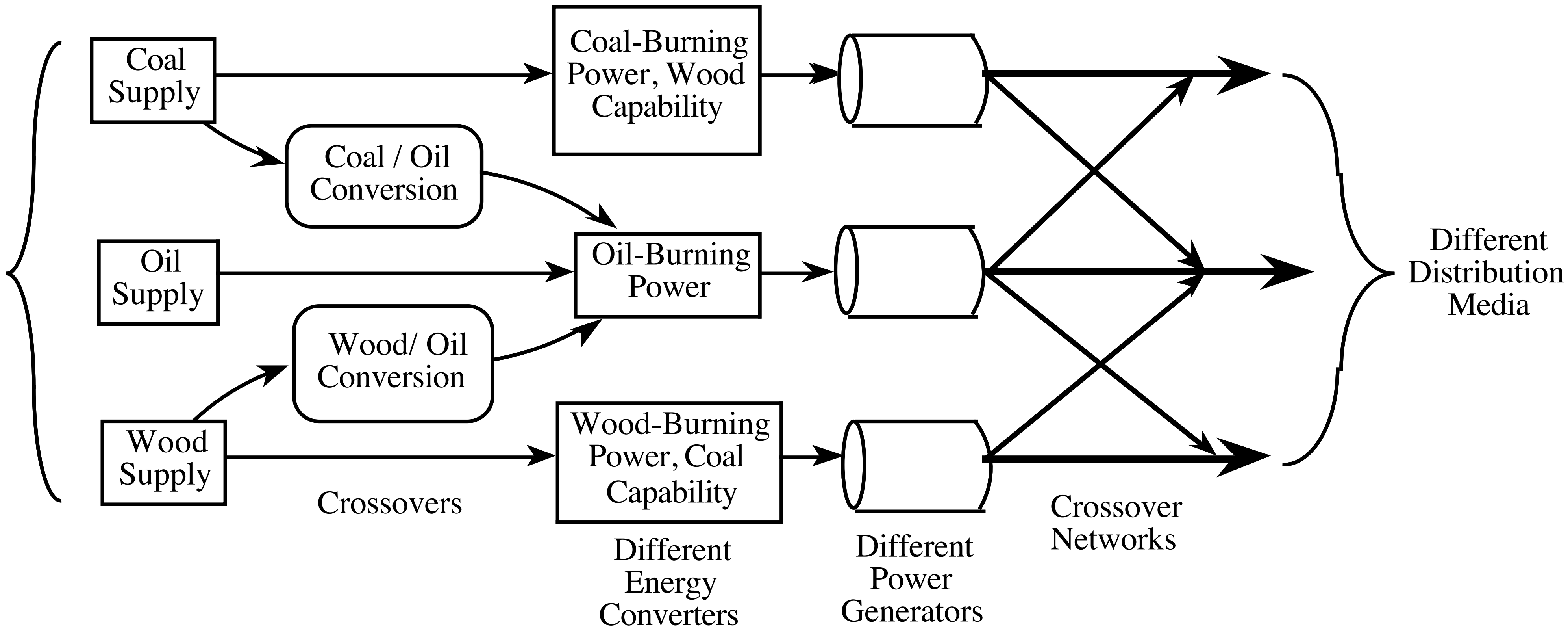
Step 6.1 Enhance Cohesives

- Perceived good remuneration, including thanks
- High morale, pride, esteem within the community
- Good Working Conditions
- Comprehensive Infrastructure—internal communications, administration, security,
- Participation in management and decisions
- Full maintenance—spares, test facilities, skills
- R&D capability, looking to future needs
- Change management system, evolving the SOI in sympathy with the environment

Step 6.2 Diminish Dispersives

- Better working conditions and pay elsewhere and accessible to staff
- Lack of perceived change
- Alternative power generation sources offering more attraction within the region—cleaner, safer, less expensive, needing less skill, using more locally-available resources, etc.
- Poor performance in primary role of generating clean, safe, affordable, continuous power
- Lack of support to maintain, modify and evolve technology within power generation system over time.
- Inability to dispose of residues satisfactorily.
- Failure of region to flourish, even when supplied with affordable power.

Step 7. Adding Connected Variety



- Promoting connected variety for long-lived stability

Conclusion

- May cost more—may also create new business
- Comprehensive
- Outward Looking
- Anticipates "White Elephants"
- Promotes Environmental Harmony and System Longevity
- Now you have seen it—isn't it ***obvious!?***
- ***Why would you do anything else?***