Mass and Energy Integration in Eco-Industrial System by Self-Organization

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Traditional Industrial System  ➔  Eco-Industrial System

The evolution is by mass, energy, information integration among the members in the system
Increasing resource & energy efficiency
Reducing waste discharged
### Mass & Energy Integration Approaches in Eco-Industrial Systems

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Complex Adaptive System (CAS) theory
Eco-Industrial System ——
A Complex Adaptive System (CAS)

- Members of eco-industrial system are agents, which
  - have self-learning and self-decision abilities
  - Interact with other agents extensively by material/energy/cash/information exchanges
  - evolve to satisfy environment (environment adaptabilities)
- System attributes (e.g. structures, functions) emerge from its members interactions
- Adaptability of agents leads to complexity of system
Eco-Industrial System Evolution Process Study by Applying Complex Adaptive System Theory

Research contents
• develop eco-industrial system evolution model
• analyze influence factors based on the model simulation
• study eco-industrial system evolutionary scenarios

Purpose
• to illustrate self-organization process
• to support policy and regulation making to promote the development of eco-industrial system
General Model of Enterprise Agent

- Knowledge Base, Data Base
  - Virgin materials
  - Reused materials
  - Virgin energy
  - Residual energy

- Goals
  - Economic Goals
  - Environmental Goals
  - Social Goals
  - Products
    - Waste liquids
    - Waste gases
    - Waste solids

- Attributes
  - Costs
  - Production Techniques
  - Production Capability

- Behaviors
  - Production
  - Treatment
  - Purchase
  - Material
  - Decision

- Data Acquire
  - Information Acquire
Information Exchange Platform - to realize agent interactions

Agent 001 → Information Exchange Platform → Agent 002

Agent 003 → Information Exchange Platform → Agent 004

Agent xxx

Agent 001

Acquire Information

Handle Information

If <Condition 1>
Behavior 1;
If <Condition 2>
Generate Information
If <Condition 3>
Send Information

Information from other agents

Information to other agents
Multi-Agent Based Simulation Flow Diagram

Start

Calculate/Update attributes of each agent

Exchange information (demand/supply, regulation, etc) with other agents

Handle information received Make decision and take actions to response to exterior changes

End Simulation?

End

next time step

Calculate/Update attributes of whole system

No
Simplified Model of Enterprise Agent Concerning Only Water Usage and Wastewater Treatment

- Water prices
  - Policy, regulation

**Information**
- Virgin water
- Water from other agents

**Water recycled/reused inside enterprise agent**

**Attributes**
- Flowrate, quality, cost of water of different usages
- Total cost of water consumption, of water recycle/reuse/treatment
- etc.

- Minimize water consumption
  - Minimized water related cost

**Goals**
- Waste water discharged
- Waste water to other agents

**Behaviors**
- Make decision whether adopt water saving measures
- Recycle/reuse cooling water
- Send/Receive water to/from other agent for treatment

- Water prices
  - Policy, regulation
An Interaction Example between Two Agents

Event e: agents invest for recycling cooling water together;

Event f: agent get benefit from provide cooling water recycle service to the other;

Event g: agent who receive service from the other has to pay

Two agents both get benefits from the cooperation.
Whole System’s Attribute Illustration

Diagram of whole system water related cost changed vs. time

Diagram of whole system fresh water consumption changed vs. time

Compare Scenarios with different agent response to exterior environmental changes

(1) Agents take no actions
(2) Agents take actions only within interior
(3) Agents take actions not only within interior but also seek cooperation with other agents
Evolution of the Water Network

- eAgent
- eAgent using recycle water
- WTP
- wastewater
- reused water
Summary

- Self-adaptability and self-organization of enterprises promote the mass and energy integration in eco-industrial system.
- Multi-agent based complex adaptive system modeling and simulation are able to explore the evolutionary integration process in eco-industrial system and its influencing factors.
- A simple case study concerning industrial water utilization and wastewater treatment illustrated interactions among enterprise agents and a bottom-up evolitional process of the water network.