Applying Availability and Complex System Concepts Toward Sustainable Living

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Presentation Objectives

- Share with the audience my interests in sustainable living
- Show why thermodynamic availability and complex system concepts could be used to enable sustainable living
- Discuss my research interest and solicit from the audience comments and suggestions about the direction for the research and the feasibility of the desired outcome.

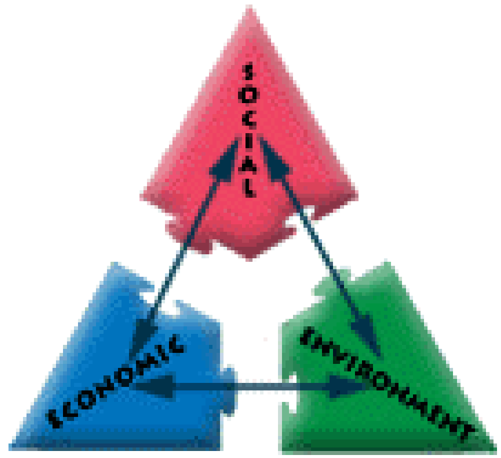
Summary Slide

- Sustainability, what does it mean
- Brief review of thermodynamics
- Thermodynamics, from an energy engineer's perspective
- Availability overview
- Availability case study
- Applying availability analysis to sustainable economic activities
- Current literature on availability and sustainability
- Conclusions
- Application to urban planning and infrastructure development

Sustainability, what does it mean

- Sustainable (Ref: Britannia.com Thesaurus)
  - Of, relating to, or being a method of harvesting or using a resource so that the resource is not depleted or permanently damaged
  - Of or relating to a lifestyle involving the use of sustainable methods.
- Sustainable development (Ref: World Commission on Environment and Development's 1987 report Our Common Future): "Development that meets the needs of the present without comprising the ability of future generations to meet their own needs".

Sustainability, what does it mean



Services	Equity	Biodiversity
Household Needs	Participation	Natural Resources
Industrial Growth	Empowerment	Carrying Capacity
Agricultural Growth	Social Mobility	Ecosystem Integrity
Efficient Use of Labor	Cultural Preservation	Clean Air and Water

Extracted from

http://www.worldbank.org/depweb/english/sd.html

Brief review of thermodynamics

- Control volume, control mass, system, environment.
- Equilibrium: a system in equilibrium is one that has not tendency to undergo change of state after a long time.
- Extensive property: The value of the property for the whole system is the sum of the property values for the subsystems. It has value regardless of whether or not the system is in equilibrium. E.g. M, V, S, U.
- Intensive property: The value of the property is independent of the size of the system. It only has meaning for systems in equilibrium states, e.g. P, T.

Brief review of thermodynamics

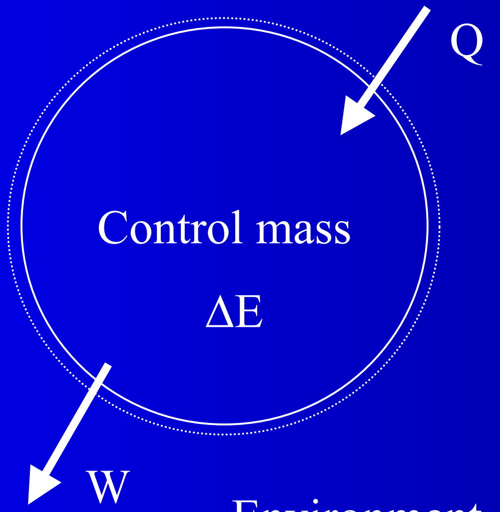
- Reversible process: A process is reversible if after it has taken place, the system and surroundings can be restored to their initial states.
- Work and heat are describable only at system boundary. They exist only while the system (or control region) and the surroundings <u>interact</u>.
- Entropy: $\Delta S = Q_{rev}/T$. Entropy is defined only for equilibrium states.

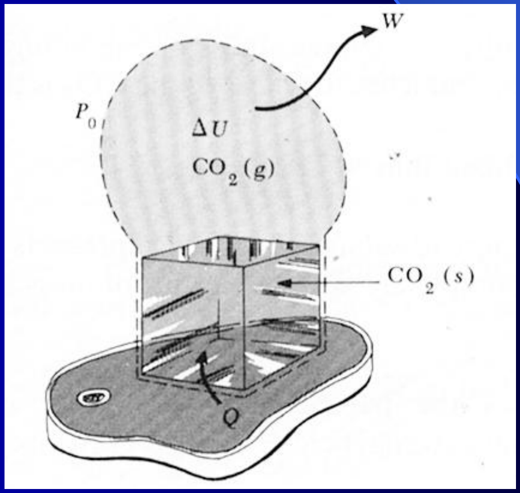
Brief review of thermodynamics

- Zeroth law – systems in thermal equilibrium (no energy transfer as heat) must have the same temperature.
- First law – the total energy of a system and its surroundings is conserved.
- Second law – entropy can be produced but not destroyed.
- Third law – the entropy of any pure substance in thermodynamic equilibrium approaches zero as the temperature approaches zero.

Thermodynamics, from an energy engineer's perspective

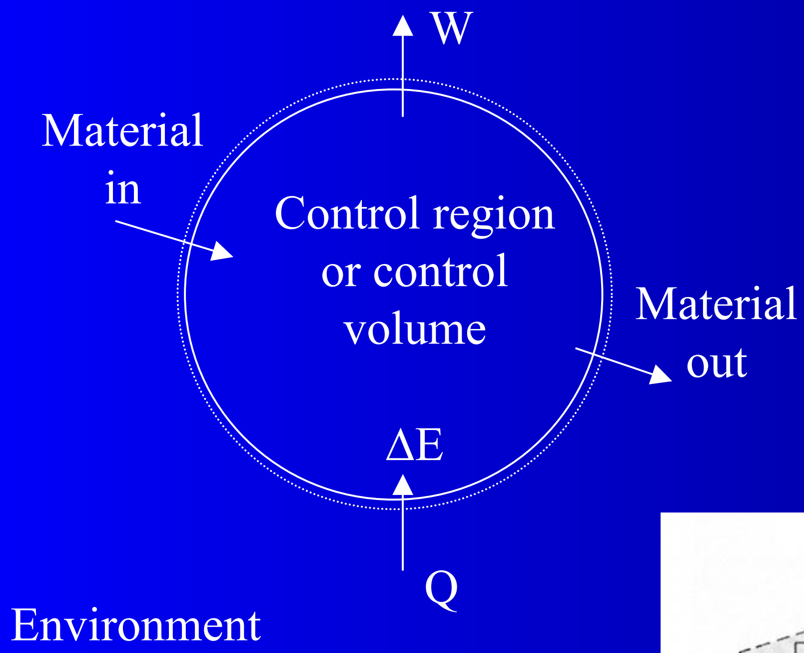
Control mass analysis and example



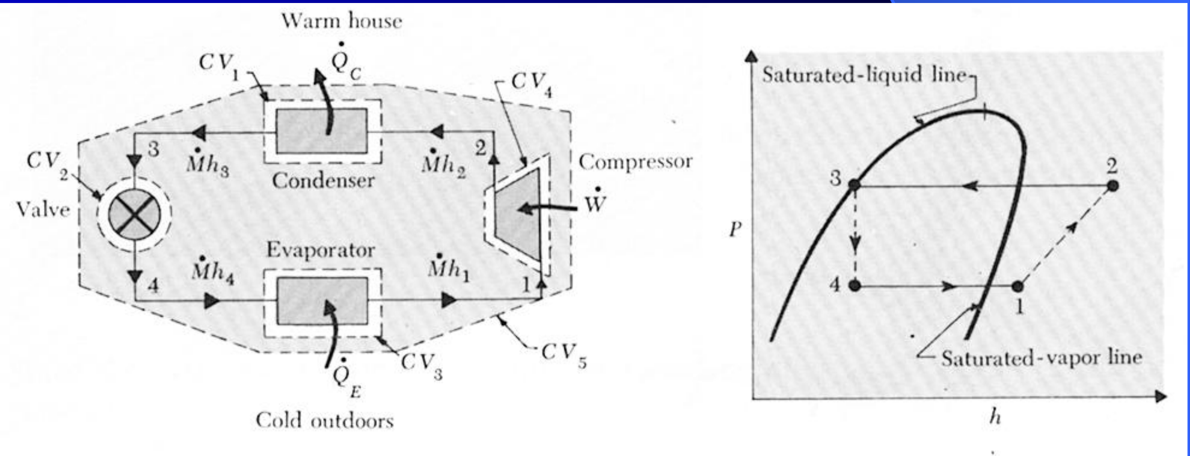


Reynolds & Perkins p. 109

Thermodynamics, from an energy engineer's perspective



Control volume analysis and example



(a) *The heat pump* (b) *The process representation*

Reynolds & Perkins p. 140

Brief review of thermodynamics

- Thermodynamics is concerned with energy and its transformations. The laws are restrictions nature imposes on all such transformations.
- 1^{st} Law allows energy-balance analysis to predict the change in state of a system due to transfers of energy as heat and work, or to spontaneous internal changes.
- 1^{st} Law does not show whether a process is possible or not. It treats work and heat interactions as equivalent forms of energy in transit.

Brief review of thermodynamics

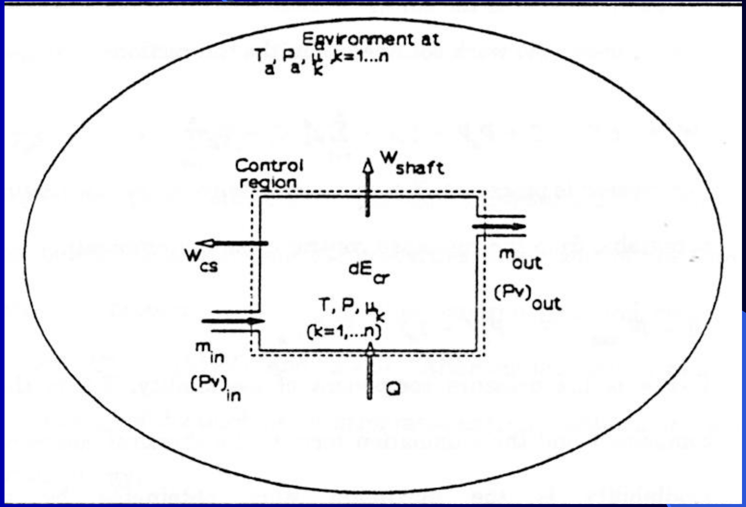
- 2nd Law states that physical systems tend toward a state of disorder. It shows the directions for chemical reactions and heat transfer, and why certain processes cannot occur.
- However 2nd Law does not explain how complex systems could arise spontaneously from less ordered states, such as living systems and their evolution.
- Prigogine: Self-organization can takes place when a system is far away from equilibrium and jump to new states with new structures. As long as systems receive energy and matter from an external source, nonlinear systems (or dissipative structures) can go through periods of instability and then self-organization, resulting in more complex systems whose characteristics cannot be predicted except as statistical probabilities.

Availability overview

- Thermodynamic availability (exergy) is the maximum possible work conversion of disordered energy into ordered energy.
- Availability analysis, is a method to account for the quality (or work potential) of energy. It applies the 1st & 2nd Laws to obtain an upper limit on the amount of power which could be obtained from a device, given the inlet and discharge states.
- Quality of energy ≡ capacity to cause change

Availability overview

Control region (or control volume analysis



$$\Delta A_{cr} = \sum_r (1 - \frac{T_a}{T_r}) Q_r +$$

Availability associated with heat transfer

$$\sum_{in} [m\{h - T_a s)]_{in} - [m\{h - T_a s)]_{out} -$$

Availability associated with flow of matter into and out of the control region

$$\Delta E_{cr} + P_a \Delta V_{cr} - T_a \Delta S_{cr} -$$

$$\sum_k (\mu_k^a - \mu_{ka}) N_k$$

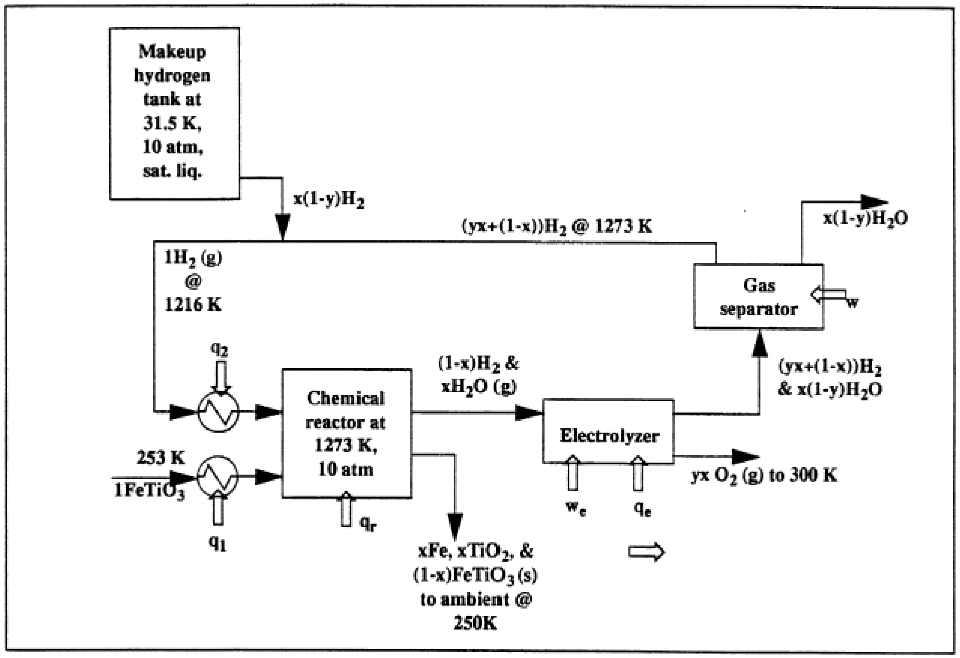
Non-flow availability in the control region

Availability overview

- For a material supply stream, the smaller its availability value, the closer it is to environmental conditions. Thus in order to reach a given state away from the environment, the more energy is needed.
- For a product stream, the larger its availability, the farther it is from the environmental conditions, therefore the greater its energy potential.

Availability analysis case study

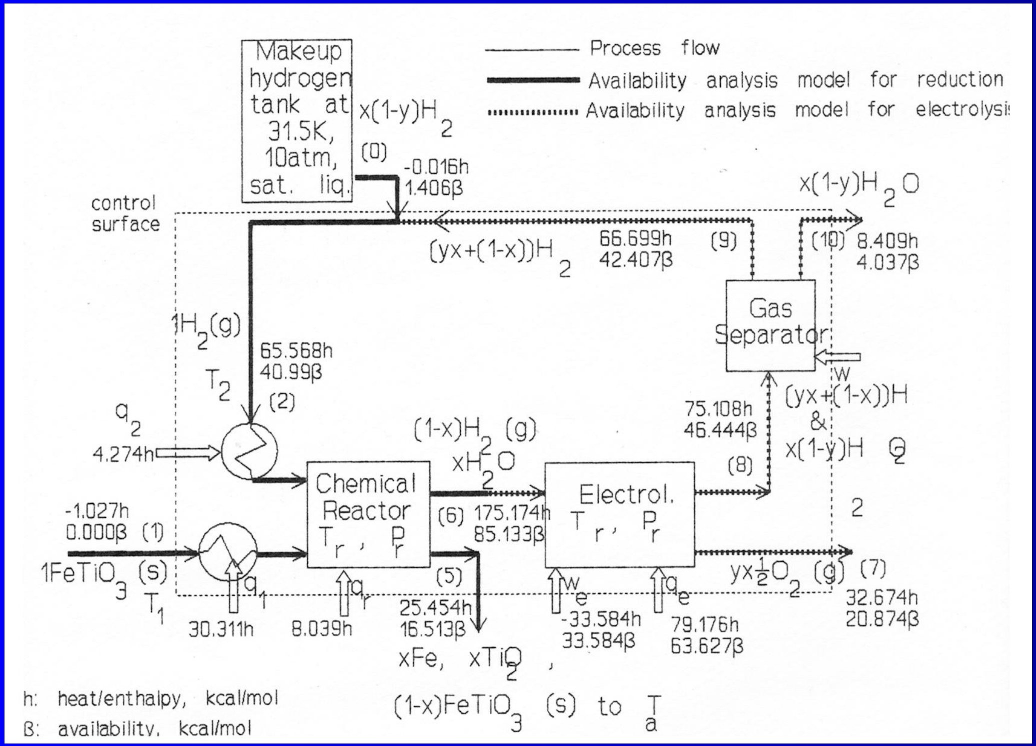
Hydrogen reduction of lunar ilmenite



Ilmenite is extracted from lunar regolith. It is then passed thru a reactor at high temperature to react with hydrogen. Water vapor formed in the reaction is then electrolyzed to separate the hydrogen and oxygen. The hydrogen is returned to the reactor. The oxygen is then cooled and sent to storage in gaseous state or liquefied and stored as liquid. [Based on Conceptual Design of a Lunar Oxygen Pilot Plant by Eagle Engineering Inc. 1988]

Availability case study

Availability analysis model for the lunar oxygen production process



Reference: Wong-Swanson

Assumptions:

•2 Mgram/month O_2 production rate, 14 working days/month. This gives O_2 flow rate of about 6 kg/hr. From this the flow rates for the other components can be obtained.

•Per pass yield of H_2 is about 10% at 1273K an 10atm

Estimated power requirement is 56kW

This requirement could be reduced with heat integration. However this has to be trade off with mass constraints.

Slag from the process may be used as building material for shielding from cosmic rays.

Availability case study

- Uses energy balance, mass balance & 2nd law to obtain energy and availability values and material flows at each state in the process.
- System design perspective
  - Holistic view of the design and development of the infrastructure, ie., not just design a power system for one process but look at all potential activities to see how they may be related
  - Tradeoff between design requirements and constraints
    - Power requirement
    - Lift-off mass from earth
    - Impact to the lunar environment
- Interactions between subsystems within the system and between the system and the environment
- Flows of materials and resources, their production, consumption, disposal

Applying availability analysis to sustainable economic activities

- Availability analysis provides the tool to
  - Examine energy and material flows between the system and its environment, and also between systems and subsystems
  - Identify elements that have the highest energy potential to be exploited
  - Employ a holistic view to infrastructure development
- Economic activities take energy and material resources from nature, transform them into useful products, and generate waste heat and waste products into nature.
- Therefore apply availability analysis to track human activities in the production, consumption and waste disposal, to maximize the use of the energy potential, extend limited resources, and reduce waste.

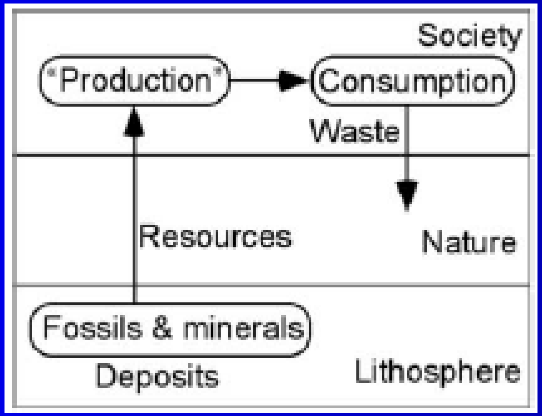
Current literature on availability and sustainability

- Literature search of combined availability & sustainable development work has just begun. My favorites so far are:
  - James Kay: http://www.jameskay.ca/ - Kay developed with the SOHO system to describe ecosystem. Website lists publications Kay authored or co-authored related to thermodynamics and ecology, complexity and self-organization. Research include: "thermodynamics of the self-organization of living systems using the ideas of complex systems theory, particularly non-equilibrium thermodynamics".
  - Goran Wall: http://exergy.se/ - Includes a bibliography containing about 2034 publications relating to the concept of exergy published by 1992. Also has a list of publications authored or co-authored by Wall on many of his exergy & sustainable development projects.

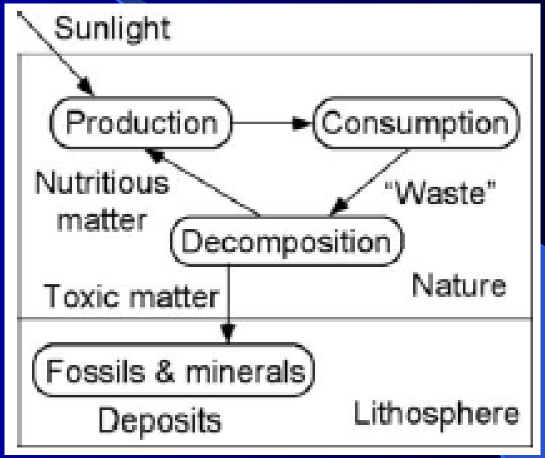
Current literature on availability and sustainability

- Goran Wall
  - Concept of sustainability is examined with relation to exergy flows on the earth, ie., the use of energy and material resources in human society are treated as flows out of and into the environment.
  - 1st & 2nd laws say that "nothing disappears and everything disperse". Natural resources are mined, used and become waste in a one-way flow.
  - A sustainable society requires the use of exergy of emissions as in indicator of environmental effects. Exergy shows the losses of a process, the emissions to the environment and which are to be minimized.

Current literature on availability and sustainability



Resource use by society



Resource use by nature

From Wall & Gong, "On exergy and sustainable development – Part 1: Conditions and concepts", Exergy, an International Journal, 1(3) (2001) 128-145

Current literature on availability and sustainability

- James Kay
  - In his doctoral work in 1984, he proposed that one has to view the ecosystems as complex adaptive self-organizing hierarchical open (SOHO) systems
  - Nested hierarchical model to describe the combined ecological and societal system
  - Self-organizing dissipative processes emerge whenever sufficient exergy is available to support them.
  - An open system with high quality energy pumped into it is moved away from equilibrium but nature resists movement away from equilibrium. At some point the open systems responds with spontaneous emergence of new, reconfigured organized behavior. At some other critical distance from equilibrium the system moves from self-organizing to chaotic behavior.
  - Surface temperature can be used to demonstrate ecosystems develop so as to degrade exergy more effectively.

Conclusions

- Resources are finite and that the environment, the thermodynamic sink is not infinite
- Sustainable issues cannot be discussed in isolation
  - Every system is a component of another system and is itself made up of systems.
- Design of human activities must consider the nested interdependencies among the different activities and between the activities with the ecosystem.

My research interest - application of 2nd Law & Complex Systems to urban planning and infrastructure development

- Scenario: clusters of small economic activities developed around distributed power generation systems with these activities providing synergism to each other.
  - Is it possible to develop a model of human activities that show the nested interactions and dependencies among different activities and between the activities and the environment?
  - In so doing, could we identify potential matches among different activities such that the energy potential of a waste energy/material stream from one activity could be used as input stream in another? Can these coupling be adaptive?
  - This may affect where economic activities may be located and how their infrastructures are designed.
- Goal is to enable sustainable living via reducing the amount of non-renewable resource consumption and the waste products dumped into the environment.

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Ecosystem & sustainable development

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