Exergy Sustainability

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Introduction: My Filters/Biases

- Aerospace engineer by training
  - Dynamics, Controls, and Optimization
  - Path dependent

- Looking for a driving/dominant input for a controller design (stability; single point failure)

- Applying it to self-organizing, complex adaptive systems
Fundamental Driver for Survival

**Exergy is the elixir of life.**

- **Exergy** – *that portion of energy available to do work* (i.e., ordered energy that is out of equilibrium with its environment; Hydro-power).

- **Elixir** – a substance held capable of prolonging life indefinitely (i.e., sustainable; fountain of youth).
Fundamentals of Thermodynamics

- Insights from the Laws of Thermodynamics
  
  - The energy of the Universe is constant.
  
  - The entropy of the Universe tends to a maximum.
Fundamentals of Thermodynamics (Cont.)

• Said another way:

I. “Energy” can be neither created nor destroyed, only changed from one form to another.

II. In using any form of Energy, it is not all “Available” to perform useful “Work”. A portion of it is “Unavailable” and must be discarded, usually in the form of “Heat”.

III. All processes and activities involve Energy changes and hence must obey Laws I and II. These changes always result in the degradation of some Available Energy into Unavailable Energy.
These insights have been likened to being in a one-sided poker game with Mother Nature, where the stakes are Exergy.

I. You can’t win. (You cannot get more out than you put in.)

II. You can never break even. (The “House” always takes a percentage of the stakes.)

III. You can’t even get out of the game. (All of existence involves Exergy.)
Confusing Energy and Exergy

- Economics: Looking for a scarce resource
  - Energy is conserved; not a scarce resource
  - Exergy is consumed/degraded; Exergy is a scarce resource.

*WHY??*
Confusing Energy and Exergy (Cont.)

• **Efficiency: 2nd Law versus 1st Law**
  
  ➢ A second law efficiency is the ratio of the minimum amount of available work required to do a particular job to the amount of available work used to do the job.
  
  ➢ Contrast this with a first law efficiency which is the ratio of energy out to energy in.

• **Decision-making via an optimization process**
Energy Surety

• The survival of your lifestyle.
Energy Surety (Cont.)

• **The survival of your lifestyle.**

  - Cheap fossil fuel (i.e., coal, oil) **IS** the elixir that has enabled your lifestyle. **Replacement??**
  
  - Present infrastructures are designed for fossil fuel.
  
  - **Goal:** *Long-term predictable business plan*
  
  - **Path:** Plug ‘n’ Play Power from All Exergy Sources via a Flexible, Adaptive Infrastructure.
From an engineering point of view, a person is an exergy parasite in the biosphere host that is trying to order the world around him/her.

**Autonomous Mars Rover**

- **Available Power In**
  - Solar
  - 12 Volts
  - 1 Amp

- **PV Solar Cells**

- **Super Capacitor (Storage)**
  - 12 Volts
  - 3 Amp

- **Required Power Out**
  - Robot Mobility

**Autonomous Man on Earth**

- **Available Power In**
  - Solar

- **Earth**

- **Fossil Fuel (Storage)**

- **Required Power Out**
  - End Uses

*NOTE: Required Power Out > Available Power In; Impedance/Capacity Mismatch*
What is Surety?

• It’s about doing a job and serving a mission…
  – Under constraints (e.g., legal or procedural)
  – And with limited resources (e.g., budget/schedule)
• And being successful
  – Providing required functionality
  – Being efficient
  – Other requirements (e.g., aesthetics)
• But at the same time avoiding catastrophic loss
  – Safety/security (inadvertent/intentional)
  – System poses acceptable residual risk
• In the context of the long-term.
Surety and Decision-Making:
Fundamental Dichotomy of Life

- **First need**: Create order to find and harness exergy.

- **Second need**: Degrade (consume) exergy; create entropy (disorder) to survive.

- **Dichotomy**: How do I create order and disorder at the same time in an optimal way?
  
  - The “Tyranny of the OR” versus the “Genius of the AND”.
  
  - Dialectic synthesis; Transcendence of dichotomies
  
  - Learn fundamental patterns of “Order and Disorder” (i.e., farming; water cycle)
Multi-Criteria Optimization

- **Requirement**: Need at least two competing criteria for interesting decision-making and learning.

- **Short-term value**: Economics of cost/profit

- **Long-term value**: Sustainability

- **Goal**: *Survival* and *Predictability* of the Future given all of the *Uncertainty*.

- **Dialectic synthesis**: “Live for today while planning for the future”.

[Image of American flag]
Our Systems Approach to Energy Surety Involves Looking at Several “Indicators of Value”

What Do You Value?
Optimization is in the eye of the beholder!
Transition Plan for Lifestyle Support System

- Fossil fuel to synfuel to $\text{H}_2$ to ??
- Plug ‘n’ play all power sources via a flexible, adaptive infrastructure.
Synfuel Production Options

Replace with heat source and H2O/CO2

Agriculture and Waste Management

Transportation

Electricity

Petrochemical

Heating and Power
The Road To A Sustainable Future Requires New Technological Insight

<table>
<thead>
<tr>
<th>Today: Open Cycle Systems</th>
<th>Near-Term: Closed Reversible Cycles</th>
<th>Mid-Term: Closed Sustainable Cycles</th>
<th>Far-Term: Fusion</th>
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<tbody>
<tr>
<td>2005</td>
<td>2015</td>
<td>2025</td>
<td>2050?</td>
</tr>
<tr>
<td>Example: Fossil Fuel Plant</td>
<td>Examples: H₂ Production, Hybrid Vehicles</td>
<td>Example: Hydropower</td>
<td>Vision: Bring Sun to the Earth (and Deep Space)</td>
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- Heat Engine
- Combustion By-Products Exhausted to Atmosphere
- Biosphere Closes the Loop

- Use closed cycles to improve efficient use of current available resources
- Equilibrium Thermodynamics

- Irreversible entropy productions (i.e., sediment) are compensated for by persistent availability
- Store excess availability for adaptability/self-organize
- Sustainable living energy infrastructure
- Non-equilibrium / irreversible thermodynamics

**Stored Exergy**

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<th>Time</th>
<th>Desired</th>
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<tr>
<td>Actual</td>
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**Possibility**

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<td>Actual</td>
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</table>

**Examples:**
- H₂ Production
- Hybrid Vehicles
- Hydropower

**Equations:**

\[ \oint dS = 0 \]
More Details
Impedance/Capacity Mismatch

Entropy Subsidies – Ragone Plot

Specific Power (Watts/kg)

Specific Energy (Watt-hrs/kg)

- Elastic Element
- Pneumatic
- Flywheel
- Internal Combustion
- Photovoltaic
- Fuel Cell
- Batteries
Sustainability: A Group Focus

- **Bruntland Commission**: A form of sustainable development which meets the needs of the present without compromising the ability of future generations to meet their own needs.

- **Technical Definition**: To provide continuous compensation of irreversible entropy production in an open system (to meet needs) with an impedance and capacity – matched persistent exergy source.

- **Survive!; Exergy Parasite**: New insights (not from classical thermo.)

  \[
  \text{Exergy Consumption Rate} = T_o \cdot \frac{d(S)}{dt}
  \]

- **Ideal Situation**: \[d S_i + d S_E \leq 0\]

- **Example #1**: Subsistence Farming

- **Example #2**: Hydroelectric Power
Life, War, and Economics

- **Goal**: Competition – “Order/Disorder Sequence and Rate”

  - Create an *Impedance Mismatch* with your competitor that is *Sustainable For You*!!!
    - Find Exergy Source (i.e., business gradient)
    - Accelerate the Duty-Cycle (i.e., product cycle)
    - Optimize Exergy Consumption Rate to order your business
    - Maximize Entropy Production Rate for your competitor