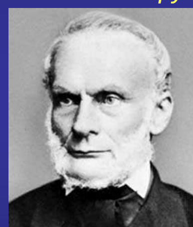
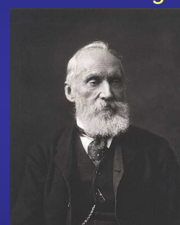
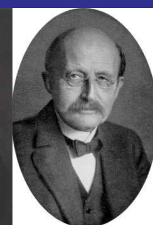
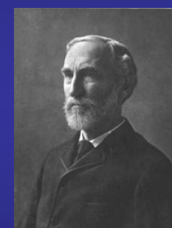
The Second Law of Energy Degradation
Including Biological and Intelligent Processes

Carnot	Clausius	Kelvin-Planck	Gibbs
1824 Heat Engine Reversibility	*1850 NO Heat from cold to hot 1865 Entropy*	*1848 Abs. Temperature 1865 NO Work from single reservoir*	*1870's Entropy, Chem.Potential Phys.Chemistry*

UIC – BioEngineering Seminar, September 4, 2009 – Chicago

www.kostic.niu.edu/Kostic-2nd-Law-Bio_Inteligence.htm

NORTHERN ILLINOIS UNIVERSITY 1895 - 1995

Prof. M. Kostic

Mechanical Engineering

NORTHERN ILLINOIS UNIVERSITY

Humanity's Top Ten Problems for next 50 years

1. ENERGY (critical for the rest nine)
2. Water
3. Food
4. Environment
5. Poverty
6. Terrorism & War
7. Disease
8. Education
9. Democracy
10. Population

2006: 6.5 Billion People

2050: 8-10 Billion (10^{10}) People

YES! Thermodynamics

an almost forgotten science
will provide vision for the future energy solutions

FUNDAMENTALS & APPLICATIONS of ENERGY

… a science of ENERGY

… the Mother of all sciences

… check-and-balance ENERGY accounting

… Energy efficiency enhancement and optimization

… provides VISION and future ENERGY solutions

Thermodynamics …

The classical, phenomenological Thermodynamics today, almost a forgotten science, has unjustifiably a dubious status. Many modern physicists regard classical Thermodynamics as an obsolete relic. Often, mostly due to lack of subtle comprehension, the Thermodynamics is considered as an engineering subject and thus not as the most fundamental science of energy and nature.

Thermodynamics …

Einstein, whose early writings were related to the Second Law, remained convinced throughout his life that "*Thermodynamics is the only universal physical theory that will never be refuted.*" Many other renowned physicists have been impressed by the universal and indisputable validity of Thermody-namic principles.

Thermodynamics …

Apart from the view that Thermodynamics is obsolete, *there is a widespread belief among scientists in Thermodynamics' absolute authority*. Namely, the phenomenological Laws of Thermodynamics have much wider, including *philosophical significance and implication*, than their simple expressions based on the experimental observations..

Thermodynamics …The 2nd Law

"It is crystal-clear (to me) that all confusions related to the far-reaching fundamental Laws of Thermodynamics, and especially the Second Law, are due to the lack of their genuine and subtle comprehension" (by *M. Kostic*)

What is Energy ?

If one could expel all energy out of a physical system … then empty, nothing will be left …

… so ENERGY is EVERYTHING … $E=mc^2$

Definition of Energy

"Energy *is a fundamental property of a physical system and refers to its potential to maintain a material system identity or structure (forced field in space) and to influence changes (via forced-displacement interactions, i.e. systems' re-structuring) with other systems by imparting work (forced directional displacement) or heat (forced chaotic displacement/motion of a system molecular or related structures).* Energy exists in many forms: electromagnetic (including light), electrical, magnetic, nuclear, chemical, thermal, and mechanical (including kinetic, elastic, gravitational, and sound).

.

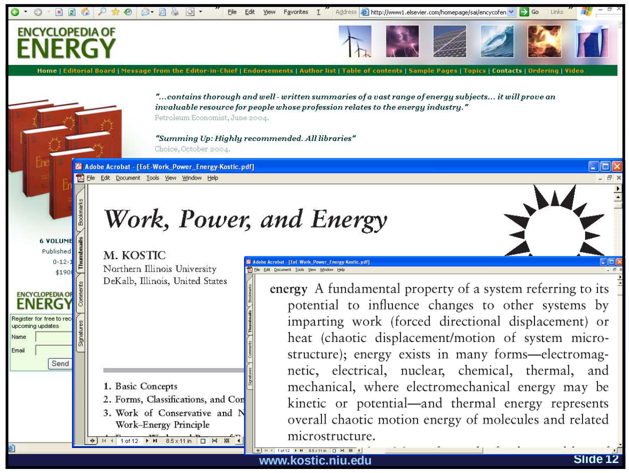
"... Energy is the "building block" and fundamental property of matter and space and, thus, the fundamental property of existence. Energy exchanges or transfers are associated with all processes (or changes) and, thus, are indivisible from time.**"** (by *M. Kostic)*

Definition of Entropy

"Entropy *is an integral measure of (random) thermal energy redistribution (due to heat transfer or irreversible heat generation) within a system mass and/or space (during system expansion), per absolute temperature level.* Entropy is increasing from orderly crystalline structure at zero absolute temperature (zero reference) during reversible heating (entropy transfer) and entropy generation during irreversible energy conversion, i.e. energy degradation or random equi-partition within system material structure and space." (by *M. Kostic)*

The Grand Law of Nature

The **universe consists of local material structures** in forced equilibrium and their interactions via forced fields. The **forces are balanced at any time** (including inertial - process rate forces) thus **conserving momentum**, while **charges/mass and energy are transferred and conserved** during forced displacement in space all the times, **but energy is degraded** as it is redistributed (transferred) from higher to lower non-equilibrium potential towards equilibrium (equi-partition of energy). (by M. Kostic)



Encyclopedia of Energy Engineering DOI:10.1081/E-EEE-120042341
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Energy: Global and Historical Background

Milivoje M. Kostic
Department of Mechanical Engineering, Northern Illinois University, DeKalb, Illinois, U.S.A.

Physics of Energy

Milivoje M. Kostic
Department of Mechanical Engineering, Northern Illinois University, DeKalb, Illinois, U.S.A.

Abstract
The concept and definition of energy are elaborated, as well as different forms and classification of energy are presented. Energy is a fundamental concept indivisible from matter and space, and energy exchanges or transfers are associated with all processes (or changes), thus indivisible from time. Actually, energy is "the building block" and fundamental property of matter and space, thus fundamental property of existence. Any and every material system in nature possesses energy. The structure of any matter and field is "energetic," meaning active, i.e., photon waves are traveling in space, electrons are orbiting around an atom nucleus or flowing through a conductor, atoms and molecules are in constant rotation, vibration or random thermal motion, etc. When energy is exchanged or transferred from one system to another it is manifested as work or heat. In addition, the First Law of energy conservation and the Second Law of energy degradation and entropy generation are presented along with relevant concluding remarks. In summary, energy is providing existence, and if exchanged, it has ability to perform change.

4th IASME/WSEAS International Conference on ENERGY, ENVIRONMENT, ECOSYSTEMS and SUSTAINABLE DEVELOPMENT (EEESD'08)
Algarve, Portugal, June 11-13, 2008

Sadi Carnot's Ingenious Reasoning of Ideal Heat Engine Reversible Cycles

MILIVOJE M. KOSTIC
Department of Mechanical Engineering
Northern Illinois University
DeKalb, IL 60115
U.S.A.
kostic@niu.edu; http://www.kostic.niu.edu

Abstract: - Sadi Carnot, at age 28, published in 1824, now famous *"Réflexions sur la puissance motrice du feu (Reflections on the Motive Power of Fire),"* which is much more important than what it appears at first. It may be among the most important treatises in natural sciences. At that time, when heat was considered as indestructible caloric and the energy conservation law was not known, when heat engines were in initial stage of development with efficiency of less than 5%, the confusion and speculations flourished. Carnot's reasoning of reversible cycles is in many ways equal if not more significant than the Einstein's relativity theory in modern times. It led to discovery of Thermodynamic absolute temperature and entropy, and the far-reaching Second Law of Thermodynamics. No wander that Carnot's work was not noticed at his time, when his ingenious reasoning of ideal heat engine reversible cycles is not fully recognized, and may be truly comprehended by a few, even now. Additional reasoning and conclusions are also presented here.

Sadi Carnot's far-reaching treatise of heat engines was not noticed at his time and even not fully recognized nowadays

In 1824 Carnot gave a full and accurate reasoning of heat engine limitations almost two decades before equivalency between work and heat was experimentally established by Joules in 1843

Sadi Carnot laid ingenious foundations for the Second Law of Thermodynamics before the Fist Law of energy conservation was known and long before Thermodynamic concepts were established.

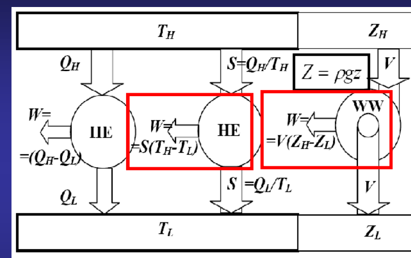


Fig. 1: Similarity between an ideal **heat engine** (HE) and a **water wheel** (WW).

$$W = W_{netOUT} = Q_{IN} \cdot f_c(T_H, T_L)$$

$$\eta_{Ct} = \left.\frac{W_{netOUT}}{Q_{IN}}\right|_{Max} = \left.\underbrace{f_c(T_H,T_L)}_{Qualitative\ function}\right|_{Rev.} \quad (1)$$

"The motive power of heat is independent of the agents employed to realize it; its quantity is fired solely by the temperatures of the bodies between which is effected, finally, the transfer of the caloric."

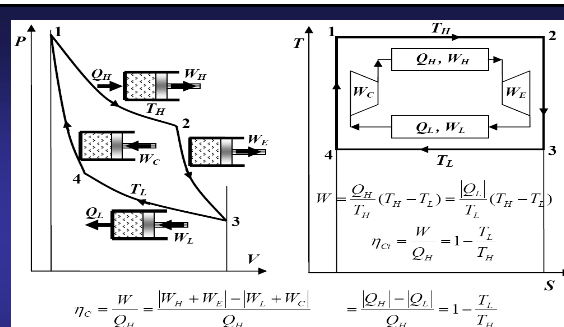


Fig. 2: **Heat-engine ideal *Carnot* cycle**: note thermal and mechanical expansions and compressions (the former is needed for net-work out, while the latter is needed to provide reversible heat transfer).

$$\{Q_H, Q_L, W_C\} \underset{\text{IF REVERESED}}{\Leftrightarrow} \{-Q_H, -Q_L, -W_C\} \quad (2)$$

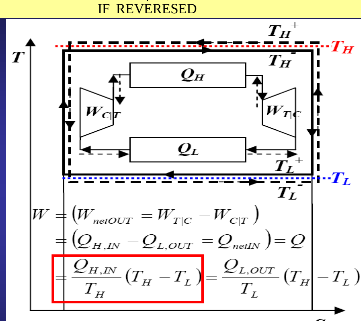
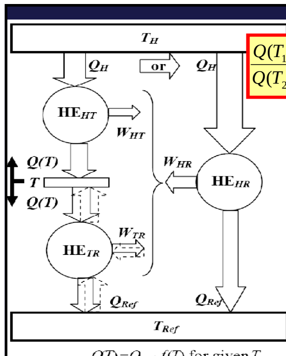


Fig. 3: **Reversible Heat-engine** (solid lines) and **Refrigeration** *Carnot* cycle (dashed lines, reversed directions).
Note, $W_H = W_L = 0$ if heat transfer with phase change (compare Fig.2).



$$\frac{Q(T_1)}{Q(T_2)} = \frac{Q_{Ref} \cdot f(T_1)}{Q_{Ref} \cdot f(T_2)} = \left.\frac{f(T_1)}{f(T_2)}\right|_{f(T)=\theta=T} = \frac{T_1}{T_2} = \frac{Q_1}{Q_2}$$

The Carnot ratio equality *above , is* ***much more important than what it appears at first****.*
Actually it is probably ***the most important equation in Thermodynamics and among the most important equations in natural sciences****.*

Fig. 5: For a fixed T_H, T_{Rref}, Q_H, and Q_{Ref}, the $Q(T)$ is proportional to Q_{Ref} (efficiency is intensive property) and an increasing function of T for a given T_{Ref}.

Clausius (In)Equality

$$\left(W_{Irr} = \oint \delta Q_{Irr}\right) \leq \left(\oint \delta Q_{\text{Rev}} = W_{\text{Rev}}\right)$$

$$\oint \frac{dQ}{T}\bigg|_{Irr} \leq \underbrace{\left(\oint \frac{dQ}{T}\bigg|_{\text{Rev}} = 0\right)}_{Eq.(10)} \quad or \quad \underbrace{\oint \frac{dQ}{T} = -S_{Gen} \leq 0}_{\substack{\text{Any Cycle} \\ \text{Clausius Inequality}}} \qquad (13)$$

$$\underbrace{-\oint \frac{dQ}{T} = S_{Gen} \geq 0}_{\substack{\text{Any Cycle} \\ \text{Clausius Inequality}}}$$

$Note,\ S_{Gen} = S_{out} - S_{in}$, $and\ \Delta S_{cycle} = (S_{in} + S_{Gen}) - S_{out} = 0$ (any cycle)

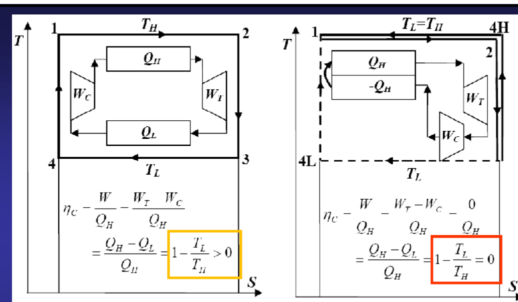


Fig. 7: Heat engine ideal *Carnot* cycle between two different temperature heat-reservoirs ($T_H > T_L$ and $W>0$) (**left**), and with a single temperature heat-reservoirs ($T_H = T_L$ and $W=0$, ideal reversible cycle) (**right**). Low-temperature thermal compression is needed (critical), not the mechanical (isentropic) compression, to realize work potential between the two different temperature heat-reservoirs, due to internal thermal energy transfer via heat ($W = Q_H - Q_L > 0$). The isentropic expansion and compression are needed to provide temperature for reversible heat transfer, while net thermal expansion-compression provides for the net-work out of the cycle.

Therefore, …

… the so called "**waste cooling-heat**" in power cycles (like in thermal power plants) is **not waste but very useful heat**, necessary for thermal compression of cycling medium (steam-into-condensate, for example), without which it **will not be possible to produce mechanical work from heat** (i.e., from thermal energy).

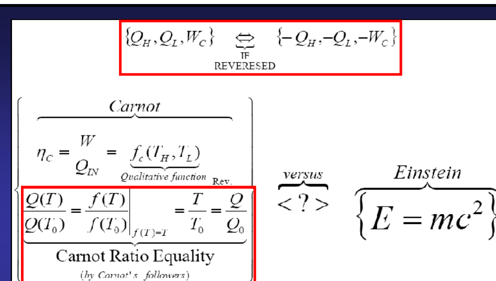


Fig. 8: **Significance of the Carnot's reasoning** of reversible cycles is in many ways **comparable with the Einstein**'s relativity theory in modern times. The *Carnot Ratio Equality* is much more important than what it appears at first. It is probably **the most important equation in Thermodynamics and among the most important equations in natural sciences.**

In conclusion …

… it is **only possible to produce work** during energy exchange **between systems in non-equilibrium**, not within a single thermal reservoir in equilibrium, for example. Actually, the **work potential is measure of the systems' non-equilibrium**, thus the work potential could be conserved only in processes if the non-equilibrium is preserved (conserved, i.e. rearranged – cycle work has to be stored eventually), and such ideal processes could be reversed, and thus named **reversible processes**.

In conclusion (2)…

… When systems come to the **equilibrium there is no potential** for any process to produce (extract) work. Therefore, it is **impossible to produce work from a single thermal reservoir** in equilibrium: **otherwise, non-equilibrium will be spontaneously created**

In conclusion (3) …

… It is only possible to produce work from thermal energy in a process between two thermal reservoirs in non-equilibrium (with different temperatures). Consequently, **if heat transfer takes place spontaneously at finite temperature difference**, without possible reversible Carnot work extraction, the latter **work potential will be permanently "lost," thus irreversibly dissipated** into thermal energy.

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In conclusion (4) …

… All real natural processes between systems in non-equilibrium have **tendency towards common equilibrium and thus loss of the original work potential, by converting ("dissipating") other energy forms into the thermal energy accompanied with entropy generation** (randomized equi-partition of energy per absolute temperature level). Due to loss of work potential in a real process, the resulting reduced work cannot reverse back the process to the original non-equilibrium, as is possible with ideal reversible processes.

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In conclusion (5) …

… Since non-equilibrium cannot be created or increased spontaneously (by itself and without interaction with the rest of the surroundings) then **all reversible processes must be the most and equally efficient** (will equally conserve work potential, i.e. conserve non-equilibrium, otherwise will create non-equilibrium by coupling with differently efficient reversible processes). The **irreversible processes will loose work potential to thermal energy with increase of entropy, thus will be less efficient** than corresponding reversible processes.

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Heat transfer is Unique and Universal:

- Heat transfer is a spontaneous irreversible process where all organized (structural) energies are disorganized or dissipated as thermal energy with irreversible loss of energy potential (from high to low temperature) and overall entropy increase.
  - **Thus, heat transfer and thermal energy are unique and universal manifestation of all natural and artificial (man-made) processes,**

… and thus … are vital for more efficient cooling and heating in new and critical applications, including energy production and utilization, environmental control and cleanup, and bio-medical applications.

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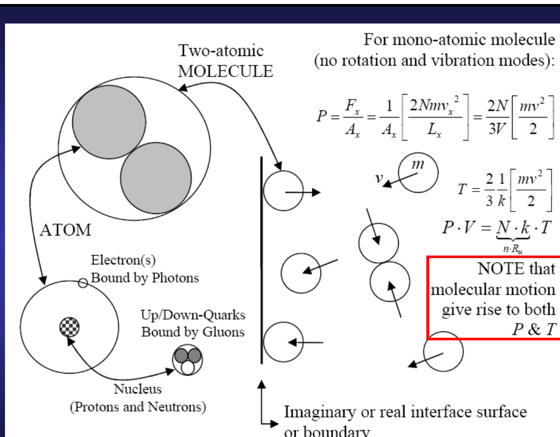

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Energy Interactions: Coupled, Adiabatic, and Caloric

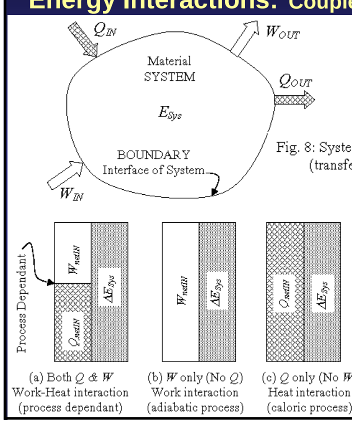

Fig. 8: System energy and energy boundary interactions (transfers) for (a) arbitrary, (b) adiabatic, and (c) caloric processes

The boundary energy transfers are process dependent for the same ΔEsys change, except for special cases for adiabatic processes with work interaction only (no heat transfer), or for caloric processes with heat interaction only (no work transfer), see Fig. 8 a,b,c.

[*Physics of Energy* (by M. Kostic), Encyclopedia of Energy Engineering, Taylor & Frances 2007]
More at: www.kostic.niu.edu/energy

REVERSIBILITY AND IRREVERSIBILITY:

ENERGY TRANSFER AND DISORGANIZATION, RATE AND TIME, AND ENTROPY GENERATION

Net-energy transfer is in one direction only, from higher to lower energy-potential, and the process cannot be reversed.

Thus **all real processes are irreversible** in the direction of decreasing energy-potential (like pressure and temperature)

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Quasi-equilibrium Process :

in limit, energy transfer process with **infinitesimal potential difference** (still from higher to infinitesimally lower potential, P).

Then, if infinitesimal change of potential difference direction is **reversed**

P+dP → P-dP

with infinitesimally small external energy, since *dP→0*,

the **process will be reversed too**, which is characterized with infinitesimal entropy generation,

and **in limit**, without energy degradation (no further energy disorganization) and no entropy generation

thus **achieving a limiting reversible process**.

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Instant Quasi-Equilibrium:

At instant (frozen) time a locality around a point in space may be considered as instant-equilibrium with instantaneous properties well-defined, regardless of local gradients.

Quasi-equilibrium is due to very small energy fluxes due to very small gradients and/or very high impedances so that changes are infinitely slow, for all practical purposes appearing as equilibrium with net-zero energy exchange.

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REVERSIBILITY –Relativity of Time:

Therefore, the changes are 'fully reversible,' and along with their rate of change and time, totally irrelevant, as if nothing is effectively changing (**no permanent-effect** to the surroundings or universe)

The **time is irrelevant** as if it does not exist, since it could be reversed or forwarded at will and at no 'cost' (no permanent change and, thus, relativity of time).

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REVERSIBILITY –Relativity of Time (2):

Real time cannot be reversed, it is a **measure of permanent changes**, like irreversibility, which is in turn measured by entropy generation.

In this regard the **time and entropy generation** of the universe have to be **related**.

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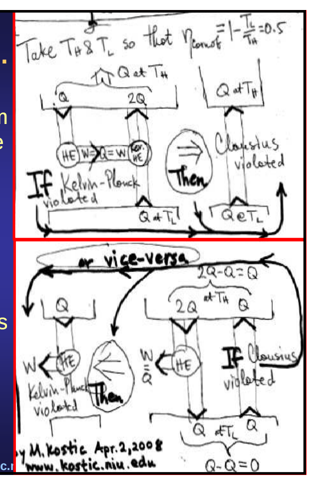
The 2[nd] Law expressions …

- Clausius: HEAT generally cannot flow spontaneously from a material at lower temperature to a material at higher temperature.
- Kelvin-Planck: It is impossible to convert heat completely into WORK in a cyclic process
- In a system process that occurs will tend to increase the total ENTROPY of the universe - The entropy of the universe tends to a maximum
- Etc …



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The 2nd Law Definition …

- **Non-equilibrium cannot be spontaneously created**. All natural spontaneous, or over-all processes (proceeding by itself and without interaction with the rest of the surroundings) between systems in non-equilibrium **have irreversible tendency towards common equilibrium** and thus **irreversible loss of the original work potential** (measure of non-equilibrium), by converting other energy forms into the thermal energy accompanied with **increase of entropy** (randomized equi-partition of energy per absolute temperature level).

Entropy …

… entropy of a system for a given state is **the same, regardless** whether it is reached by reversible heat transfer or irreversible heat or irreversible work transfer.

$$dS = \frac{\delta Q}{T} = \frac{\delta Q_{rev} + \delta Q_{gen}}{T} \quad \text{or} \quad S = \int \frac{\delta Q}{T} + S_{ref}$$

However, the **source entropy will decrease** to a smaller extent over higher potential, thus resulting in **overall entropy generation** for the two interacting systems.

Entropy …

We could consider a system internal thermal energy and entropy, as being **accumulated from absolute zero** level, by disorganization of organized or higher level energy potential with the corresponding entropy generation.

Thus **entropy** as system property is **associated with its thermal energy** (but also space).

Entropy Primer:

entropy could be **transferred in reversible** processes **along with heat transfer**, and additionally **generated** if work or thermal energy are disorganized at the lower thermal potential during **irreversible processes**.

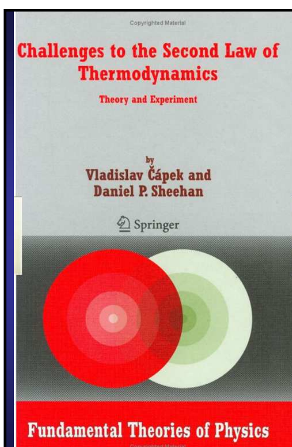
Once a process completes, any generated entropy due to irreversibility becomes (**permanent**) system property and cannot be reversed by itself (thus, a permanent change).

Entropy Primer (2):

Thus, entropy transfer is

due to reversible heat transfer and could be ether **positive or negative**,

while **entropy generation is always positive** and always **due to irreversibility**.



"The Second Law of Thermodynamics is considered **one of the central laws of science**, engineering and technology. For over a century it has been **assumed to be inviolable** by the scientific community. Over the last 10-20 years, however, **more than two dozen challenges** to it have appeared in the physical literature - more than during any other period in its 150-year history."

Nature often defy our intuition

- Without friction, clock will not work, you could not walk, birds could not fly, and fish could not swim.
- Friction can make the flow go faster
- Roughening the surface can decrease drag
- Adding heat to a flow may lower its temperature, and removing heat from a flow may raise its temperature
- Infinitesimally small causes can have large effects (tipping point)
- Symmetric problems may have non-symmetric solutions

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Living and Complex Systems

- Many creationists make claims that evolution violates the Second Law. Although biological and some other systems may create local non-equilibrium and order, the net change in entropy for all involved systems is positive and conforms to the Laws of Nature and the Second Law for non-equilibrium open systems.

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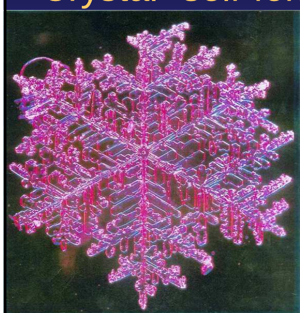
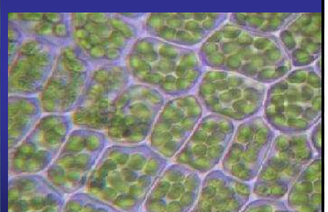
Crystal “self-formation”…





… and Plant Cells growth

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YES! Miracles are possible !

It may look ‘perpetuum mobile’ but miracles are real too …

Things and Events are both, MORE but also LESS complex than how they appear and we ‘see’ them-- it is

natural simplicity in real complexity

… we could not comprehend energy conservation until 1850s:
(mechanical energy was escaping without being noticed)

… we may not comprehend now new energy conversions and wrongly believe they are not possible:
(“cold fusion” seems impossible for now … ?)

…….Let us keep our eyes and our minds ‘open’ ……….

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YES! Miracles are possible !

… but there is **NO ideal ‘Things and Events’** …

‘Things and Events’ are both, MORE but also LESS complex than how they appear and we ‘see’ them-- it is

natural simplicity in real complexity

… there are **no ideal things**, no ideal rigid body, no ideal gas, no perfect elasticity, no adiabatic boundary, no frictionless/reversible process, no perfect equilibrium, not even steady-state process …

… there are **always processes** - energy in transfer or motion, all things/everything ARE energy in motion with unavoidable **process irreversibilities**, however, in limit, an infinitesimally slow process with negligible irreversibility appears as instant reversible equilibrium – thus, **everything is relative** with regard to different space and time scales …

….Let us keep our eyes and our minds ‘open’ ……….

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All processes are transient …

- All processes are transient (work and heat transfer in time), even Eulerian steady-state processes (space-wise) are transient in Lagrangian form (system, from input to output), but equilibrium processes and even quasi-static (better, quasi-equilibrium) processes are sustainable/reversible.

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If we are unable to observe …

- If we are unable to measure something **it does not mean it does not exist** (it could be sensed or measured with more precise instruments or in a longer time scale, or in similar stronger processes; mc^2!).
- So called "self-organizing" or entropy increasing processes appear so, since we may be unable to measure entropy change of affecting boundary environment, for such open processes.

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However, …

… the miracles are
until they are comprehended
and understood !

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Energy Future Outlook:

…a probable scenario … in the wake of a short history of fossil fuels' abundance and use (a bleep on a human history radar screen), the following energy future outlook is possible…

1. Creative adaptation and innovations, with change of societal and human habits and expectations (life could be happier after fossil fuels' era)
2. Intelligent hi-tech, local and global energy management in wide sense (to reduce waste, improve efficiency and quality of environment and life)
3. Energy conservation and regeneration have unforeseen (higher order of magnitude) and large potentials, particularly in industry (also in transportation, commercial and residential sectors)
4. Nuclear energy and re-electrification for most of stationary energy needs
5. Cogeneration and integration of power generation and new industry at global scale (to close the cycles at sources thus protecting environment and increasing efficiency)
6. Renewable biomass and synthetic hydro-carbons for fossil fuel replacement (mobile energy, transportation, and chemicals)
7. Advanced energy storage (synthetic fuels, advanced batteries, hydrogen,…)
8. Redistributed solar-related and other renewable energies (to fill in the gap…)

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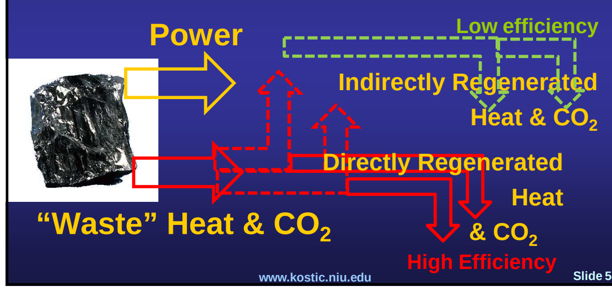
Efficient: do MORE with LESS

Improve true (2nd Law) efficiency by conserving energy potentials: REGENERATE before "diluting" and loosing it!



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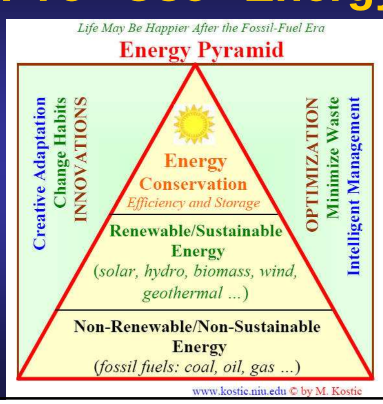
How To "Use" Energy ?



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More information at:
www.kostic.niu.edu/energy

Solar 1.37 kW/m², but only 12% over-all average 165 W/m2

Work, Power, and Energy

However, regardless of imminent shortages of fossil fuels, the outlook for future energy needs is encouraging. Energy conservation "with **existing technology**" (insulation, regeneration, cogeneration and optimization with energy storage) has real **immediate potential** to substantially **reduce energy dependence on fossil fuels** and **enable use of alternative and renewable energy sources**. There are many diverse and abundant energy sources with promising future potentials, so that mankind should be able to **enhance its activities**, **standard and quality of living**, by diversifying energy sources, and by improving energy conversion and utilization efficiencies, while at the same time increasing safety and reducing environmental pollution.
After all, in the wake of a short history of fossil fuels' abundance and use (a blip on a human history radar screen), **the life may be happier after the fossil fuel era**!
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