Keeping the Lights On: Physics and the Carbon Crisis

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Abstract

There is much evidence that the human species is presently in the midst of a global-scale "carbon crisis," due to the coupled challenges of depletion of high-available-energy fossil fuels and climate change due to our use of those fuels. I will review the evidence for this claim, and argue that physics has a positive contribution to make to solving this urgent problem.

The 1.5 Tonne PC

- In 1950s, no one foresaw huge advances in information tech (LSI, Internet, etc.) that have occurred.
- Quote from *Popular Mechanics*, 1949 [6]:

> *Where a calculator like ENIAC today is equipped with 18,000 vacuum tubes and weighs 30 tons, computers in the future may have only 1000 vacuum tubes and perhaps weigh only* $1^1/_2$ *tons.*

Where's My Jetsons Car?

- But also no one foresaw the utter lack of advances in energy tech since then.
- In the 1950s, it was assumed that energy would soon be "metreless" and abundant:
  - The Jetsons
- The cars and airplanes we have today are essentially the same as in 1960, except with improved electronics.
- About 85% of world energy still comes from fossil fuels. *Could we have done better?*

Where We are Today: The Carbon Crisis

- The dominant challenges of our time:
  - Steady depletion of highest-EROI fossil fuels.
  - Global warming and other aspects of climate change caused by CO_2 emissions.
- Collectively, the “Carbon Crisis.”
- I’ll give some background to each point in turn, and then try to say why these are problems that physicists should be interested in.

Anthropogenic Global Warming—Now

- Global warming: about 1.1℃ since pre-industrial era. (Updated Oct. 1/17.)
- Caused almost entirely by emissions of CO_2 due to fossil fuels (with contribution from deforestation, cement production).
- Current effects (generally increasing faster than scientists had predicted):
  - Warming most severe at high latitudes, especially Arctic.
  - Arctic sea ice at record low level.
  - Increased severe weather (storms, droughts, floods) as measured by insurance data.
  - Shifting climate zones.
  - Net mass loss from Greenland, Antarctica.
  - General retreat of glaciers everywhere in the world.
  - Warming and acidification of oceans.
  - Accelerating sea level rise.

AGW—The Near-Term Trends

- Near-term trends and risks of AGW:
  - Melting of permafrost could release CH_4, amplifying warming.
  - Probable gradual rise of sea level to 0.5 m – 1.0 m above present level by 2100.
  - Possible catastrophic rise of sea level (metre-scale) due to collapse of WAIS; timing very uncertain.
  - Current [CO_2] around 400 ppm associated in paleoclimate record with sea level at least 5–10 m higher than today.
  - "Tipping point" (around 2℃ above pre-industrial temp?) when changes are irreversible due to positive feedbacks.
  - Dr. Richard Somerville (Scripps): "We have 5–10 years to reduce CO_2 emissions by 80%."

AGW—How Bad Could It Get?

- Longer-term risks:
  - Near-total disintegration of ice caps, leading to:
    - Extreme sea level rise (up to $50\,\mathrm{m} \pm$).
    - Probable shut-down of oceanic circulation.
  - Global mean temperature rising to point at which human life is near-impossible in the tropics.
  - Oceanic anoxia leading to euxinia (condition in which ocean dominated by anaerobic micro-organisms producing H_2S).
  - Euxinia is associated with episodes of mass extinction in the past.
    - Current educated guess [12] is that risk of euxinia becomes significant when $[CO_2] \approx 1000 - 1200\,\mathrm{ppm}$.
    - *We do not want to go there. . . !*
    - The "good" news: technological civilization will probably collapse long before we reach 1200 ppm!

Decline of Cheap Energy

- Joseph Tainter [11]: luxuriant energy flow is necessary for complex societies to be sustainable.
- EROI: "Energy Return on Energy Investment" (Charles Hall) [1].
- $$\text{EROI} = \frac{\text{Units of usable energy recovered from a process}}{\text{Units of energy required for that process}}$$
- EROI does not measure how efficiently you use the energy.
- Oil in its heydey had EROI ≈ 100; now, conventional oil 20–30, tar sands 1.5–5.
    - We've picked the "low hanging fruit."
- Ancient Rome at its height had EROI ≈ 20 [3]; our world EROI is declining to Roman levels.

"It's the EROI, stupid!"

- Economic prosperity depends upon having a good EROI; everything we do takes energy.
- Hall [4] estimates absolute minimum EROI needed for industrial society 5–9 — *but this is merely enough for bare survival*.
- Hall's gloomy diagnosis [1, 2497]:

> *I do not see. . . anything that implies 'business as usual' (i.e., growth) as the most likely scenario. . . Even our most promising new technologies appear to represent at best minor, even trivial, replacements for our main fossil fuels at least within anything like the present investment and technological environment. . . depletion seems to be effectively trumping technological progress again and again.*

Inside the Envelope

- Many of the things that we can do to mitigate climate change and replace fossil fuels do not demand radical leaps in scientific understanding, only *political will* and *entrepreneurship*: e.g.:
  - Increases in efficiency ("the fifth fuel"), conservation, recycling.
  - Wind, solar, tidal, geothermal.
  - Biomass (though *not* corn ethanol!).
  - Reforestation on massive scale.
  - Improved fission reactors (possibly thorium-based).
  - Improved batteries, ultracapacitors, fuel cells.
- The challenge is to make what is technically possible, also politically and economically possible.

Outside the Envelope

- There are several conceivable energy technologies that demand either an unknown amount of R & D or substantial advances in physical understanding:
  - Controlled thermonuclear ("hot") fusion.
  - Inertial confinement fusion (recent billion-$ flop, sadly).
  - Cold fusion, LANR, LENR.
  - Exploitation of Hawking effect, other quantum gravity effects (highly hypothetical).
  - Zero point energy (possibly pure science fiction but worth thinking about).
- I will illustrate problems and potential with discussion of cold fusion, LENR.

The Cold Fusion Fiasco

- In 1989, Stanley Pons and Martin Fleischmann announced that they were able to produce small amounts of net heat in a table-top electrochemical device.
- Did not go through proper peer review process.
- Some (e.g., MIT) claimed they were unable to reproduce the results; other scientists claimed they could; ultimately, it was dismissed as "pathological science" to the relief of oil companies and hot fusion researchers.

Julian Schwinger

Julian Schwinger
(1918-1994)

- Julian Schwinger:
- Nobel (1965) with Feynman & Tomonoga for quantum electrodynamics; many contributions to fundamental theory; see [7], *Wikipedia*.

Schwinger & Cold Fusion

- From 1989 to his death in 1994, Schwinger wrote several papers exploring theoretical basis for cold fusion.
- Key concept: the field-theoretic "environment" for cold fusion not the same as hot fusion; argued that quantum-mechanical collective effects in lattices could (in simple terms) allow for partial shielding of nuclear charge and thus penetration of Coulomb barrier.
- His papers were rejected by *Phys Rev* and he ultimately resigned from APS in disgust at the dogmatism of the anonymous referees who tore his work to shreds without attempting to understand it.

Schwinger: Upshot

- *"The pressure for conformity is enormous. I have experienced it in editors' rejection of submitted papers, based on venomous criticism of anonymous referees. The replacement of impartial reviewing by censorship will be the death of science."*
- My personal take on this story:
  - If Julian Schwinger thought that cold fusion is probably worth taking seriously, then it is probably worth taking seriously.
  - His story is symptomatic of larger problems with current scientific research.

Case Study: LENR

- LENR: Low Energy Nuclear Reactions.
  - Aka LENT (Low Energy Nuclear Reaction Theory); LANR (Lattice Assisted Nuclear Reactions).
- Currently being studied at NASA Langley.
- Goes beyond cold fusion in considering effects of weak interactions and surface-mediated effects.
- Developed by Alan Widom, Lewis Larsen, Y. Srivastava [13, 10, 9, 5]

Gist of LENR

- Gist of the theory of Widom, Larsen, and Srivastava:
  - Low energy neutrons can change atomic number of nucleus; typical reaction sequence:

$$^4_2\mathrm{He} + 2n \rightarrow ^6_3\mathrm{Li} + e^- + \overline{\nu}_e \qquad (1)$$

  - This reaction would release about 2.95 MeV [10]; but it is (they argue) released as IR since the nuclear γ "jolt" is absorbed by collective e.m. effects; hence no dead grad students.
  - Can thereby move nuclear species up or down the periodic table, in some cases releasing lots of energy.
  - A perfected LENR technology would allow efficient and cheap transmutation of elements as well as releasing carbon-free, radioactive-waste-free energy.

The Catch

- Catch: where do we get the neutrons? We could use the following weak process:

$$e^- + p \rightarrow n + \nu_e. \quad (2)$$

- But this has a very low cross section in vacuum.
- Here's where it gets difficult. . .
  - Claim: collective quantum electrodynamics in surface of metal hydride lattice will produce "heavy" or "dressed" electrons (via vacuum polarization).
  - This greatly increases cross-section for process (2) (above).
- Harks back to Schwinger's idea: small regions of e.m. field concentrations in complex solid state device can be high enough to induce nuclear reactions.
  - This may be wrong, but it is not a stupid idea, and needs to be *properly* investigated.

LENR: The Takeaway

- It is not yet proven that LENR has a sound theoretical basis, nor is there experimental evidence that has yet found "official" acceptance.
- However, it does have a *promising* theory (Widom & Larsen) and some claims of evidence worth being taken seriously.
- A catch-22:
  - "Nobody works on it because it is fringe science—but it is fringe science because nobody works on it."
  - Same could be said for other promising but unorthodox approaches (e.g., polywell fusor).
  - Problem: how do we break this vicious circle?

Advice from Hansen & Smolin

- Hansen [2] warns that we cannot continue with BAU (Business as Usual).
- Similarly, we cannot continue with RAU (Research as Usual).
- Lee Smolin [8]:

> *Deep, persistent problems are never solved by accident; they are solved only by people who are obsessed with them and set out to solve them directly.*

- If physicists are going to contribute to the solution of the energy problem, they have to decide that it is worth doing, and take the steps necessary to solve it.

Implications for Scientific Methodology

- Many approaches must be tried. (Cf. Manhattan Project. . .)
  - This will require political will because it demands a major commitment of society's resources.
- Scientists must re-consider their priorities:
  - If the highest goal is to prevent error, then one should reject work that has the slightest chance of being wrong (as with Schwinger's experience).
  - *However*, if the highest priority is to solve a very important problem as soon as possible, then one should keep alive work that has any appreciable chance of being right.

Implications for Scientific Methodology (con't)

- Scientists must be willing to accept a higher level of intellectual risk.
- Do not reject unusual observations out of hand simply because there is no theory to explain them.
- Pay special attention to credible observations that challenge existing theory.
  - Just as coaches in professional sports are hired to be fired, scientific theories are created to be refuted, superseded, or generalized.

Implications for Scientific Methodology (con't)

- Scientists must probe the *holes* in current theory.
  - Do not confuse the absence of a rigorous theory of a process with the impossibility of that process.
  - Example: while it is not yet clear that LENR is possible, it is also not clear that it is *impossible*, and there is some evidence that it *might* be possible.
  - It needs an open-minded, thorough investigation by competent professional physicists.
  - The aim is not to find a reason to dismiss it, but to find out how to make it work despite the many practical and theoretical problems it faces.
- Possibilities like LENR need to be researched as thoroughly as quantum information science is now being researched—or more!

Implications for Scientific Practice

- As Smolin points out [8], there are many disincentives to innovation and risk-taking in the culture of physics since WWII:
  - Young physicists are discouraged from asking foundational questions: "Shut up and calculate. . . !"
  - As funding gets tighter, scientists cannot afford the risk of trying something that is not "safe," and this decreases the chances of making discoveries.
  - As new discoveries dry up, public/political support for science may decrease, a vicious circle.

"We Don't Do That Here. . . "

- In petrostates like the U.S. and Canada, R & D into non-fossil sources of energy is marginalized, under-funded, and even actively discouraged.
- Annual, global subsidy of fossil fuel industries $\approx$ \$600 billion, and yet you will be told that R & D on alternatives is "too expensive."
- The next major developments may occur in places like Japan or some European countries, which are technologically sophisticated but not beholden to vested interests in the fossil fuel industry.

Closing Thought

- *"The Stone Age came to an end, but not for a lack of stones, and the oil age will end, but not for a lack of oil."*

  — Sheikh Ahmed Zaki Yamani (2000) Former Oil Minister of Saudi Arabia (quoted by Larsen [5].)

References

Hall, Charles A.S. "Synthesis to Special Issue on New Studies in EROI." *Sustainability* 3, 2496–99, 2011; doi: 10.3390/su3122496.

Hansen, James, M. Sato, P. Kharecha, G. Russell, D. W. Lea and M. Siddall. 2007. "Climate Change and Trace Gases." *Philosophical Transactions of the Royal Society A* 365, 1925–54.

Homer-Dixon, Thomas. *The Upside of Down: Catastrophe, Creativity, and the Renewal of Civilization*. Toronto: Vintage Canada, 2006.

Inman, Mason. "The True Cost of Fossil Fuels." *Scientific American* 308(4), April 2013, 58–61.

Larsen, Lewis. "Powering the World to a Green Future." `http://www.slideshare.net/lewisglarsen`

Quote from 1949 *Popular Mechanics*, cited by Jim Meigs, http://www.popularmechanics.com/technology/engineering/news/inside-the-future-how-popmech-predicted-the-next-110-years-14831802

Rabinowitz, Mario (2003). "In Memory of Julian Schwinger." `http://arxiv.org/abs/physics/0303078`

Smolin, Lee. *The Trouble With Physics: The Rise of String Theory, the Fall of a Science, and What Comes Next*. New York: Houghton Mifflin, 2006.

Srivastava, Yogendra. "Review of Low Energy Nuclear Reaction Theories." `http://www.prometeon.it/download/YogiSrivastava.pdf`

Srivastava, Y.N., A. Widom, & L. Larsen. "A Primer for Electro-Weak Induced Low Energy Nuclear Reactions." `arXiv:0810.0159v1[nucl-th]1Oct2008`

Tainter, Joseph A. *The Collapse of Complex Societies*. Cambridge University Press, 1988.

Ward, Peter. *Under a Green Sky: Global Warming, the Mass Extinctions of the Past and What They Can Tell Us About Our Future*. New York: HarperCollins, 2007.