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WHY HYDROGEN? BECAUSE WE *CAN'T ESCAPE* CLIMATE CATASTROPHE WITHOUT IT*

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Beginning with a review of the causes, dangers and impacts of human induced (anthropogenic) climate change—with an emphasis on oceans and sea-level rise—the article moves defines the role of energy currencies and why the concept of currencies is key to identifying systemic climate change solutions.

The article then sets out a six-step rationale showing why the twin energy currencies hydrogen and electricity (hydricity) must dominate future energy systems—if we are to have a chance to escape worldwide climate catastrophe. It concludes with a few reflections on hydricity and thoughts on why a vigorous transition to hydricity has not yet begun.

Key words: climate heating; hydrogen, electricity and hydricity; positive feedback; energy currencies; non-carbon emitting energy sources; energy miracle; sea level increases.

ПОЧЕМУ ВОДОРОД? ПОТОМУ ЧТО БЕЗ ВОДОРОДА МЫ НЕ СМОЖЕМ ИЗБЕЖАТЬ КЛИМАТИЧЕСКОЙ КАТАСТРОФЫ

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Начиная с обзора причин, опасностей и последствий антропогенного изменения климата, с акцентом на повышении уровня моря, в статье анализируется роль энергетических носителей и объясняется, почему концепция носителей является ключом к выявлению системных решений по изменению климата.

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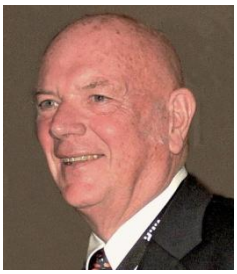
Кроме того, в статье излагаются шесть пунктов, в которых даётся обоснование того, почему водородная и электрическая энергии (*hydricity*) должны доминировать в будущих энергетических системах, при условии, что у нас будет шанс избежать всемирной климатической катастрофы. В заключение приводится несколько мыслей о *hydricity* и о том, почему активный переход к *hydricity* еще не начался.

Ключевые слова: климатическое нагревание; водород, электричество и *hydricity*; положительная обратная связь; энергетические носители; источники, не содержащие углерода; энергетическое чудо; повышение уровня моря.



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Публикации: более 100; книга «Smelling Land: водородная защита против климатической катастрофы» (2007 г.).

Nomenclature	
Greek letters	
ρ	Density of water
ν	Kinematic viscosity
φ	Angle, grad
ω	Circular frequency of rotation
Latin letters	
B	Channel width and Chord length
C_P	Turbine efficiency
C_x	Resistance coefficient
D	Turbine diameter
g	Gravity acceleration
H	Head on turbine
L	Turbine length
L_b	Blade length
n	Frequency of rotation
P	Power, capacity
R	Turbine radius
U	Flow speed
V	Linear velocity of blade
Abbreviation	
RES	Renewable Energy Sources

"We are drowning in information, while starving for wisdom," wrote Edward O. Wilson in his excellent book Consilience: The Unity of Knowledge. *This article attempts energy wisdom.*

1. Climate Heating and Sea Level Rising

I first heard "heating" rather than "warming" used by James Lovelock, the imaginative scientist who, along with Lynn Margulis, developed the GAIA [1] hypothesis of life-controlled thermal planetary equilibrium. I consider "heating" a more accurate, direct term than "warming."

1.1. The Cause

The prime cause of global heating is the continuing growth in atmospheric greenhouse gases, such as carbon dioxide (CO_2) and methane (CH_4), which trap heat in the atmosphere. Overwhelmingly, these gases are anthropogenic (human sourced). Some are indirectly anthropogenic such as livestock flatulence—but it's people who own and feed the livestock.

1.2. The Danger

If unstopped, today's accelerating climate heating *will* destroy civilization. This is not exaggeration. Consider *only* one phenomenon: rising sea levels, which is but *one consequence* of ocean heating. I'll leave aside other impacts, such as ocean acidification—the result of carbon dioxide absorption from an increasingly CO_2 loaded atmosphere.

I'm often asked, "But by how much can the oceans rise?"

Without specifying a timeframe, it's a meaningless question. And even if we set the timeline, say, in 50, 100 or even 200 years, it's still difficult to answer. That's because climate and its interconnections with other environmental constraints are highly nonlinear phenomena.

A question we *can* answer with reasonable confidence is, "To what level will the ocean rise if all the world's land-supported ice, over the Arctic, Antarctic and continental glaciers, melt?

That number has been calculated. The answer is that sea levels will increase between 70m ~ 80m [2]. That should be terrifying—especially since the latest data point out that "heating" is progressing at double the speed earlier projected [3]. Among many references, an excellent lay-explanation of the physics including outstanding visuals can be found in the "Rising Seas" article by Folger [4].

I'll first consider North America, because that's where I live. Much of North America's eastern coast will be flooded. Today the chart datum of Lake Ontario (the eastern-most of the Great Lakes) is 74 m above sea level. So, if all Earth's land-supported ice melts, Lake Ontario will become salt water. Toronto and Rochester will have salty wet feet. Chicago will be spared. Manhattan will be gone.

Turning to Russia, among her coastal disasters, the world will lose one of its greatest cultural masterpieces, St Petersburg, with its internationally renowned State Hermitage Museum and other treasures.

1.3. Wars and Plagues

Both sea level rise and climate heating will make many tropical regions uninhabitable—and result in mass migrations. Countries and regions to which fleeing migrants hope to enter will introduce legislation to slow or block immigration. In the longer term, they are likely to defend their retreating shorelines with guns, ships, missiles and aircraft.

Consequently, climate heating will lead to wars.

Moreover, global climate change will trigger diseases and probably plagues. We are seeing precursors of these today.

1.4. Can We Take Comfort Hoping Something Might Intervene to Stop Sea Level Increase?

I think not. That's because the only significant feedback mechanisms that impact ocean level increases are *positive* feedbacks—feedbacks that accelerate heating, not retard it.

Well-known positive feedbacks include melting the arctic floating ice leaving a naked, dark ocean to absorb incoming sunlight rather than white ice and snow that reflect sunlight. A second positive feedback is methane release from melting permafrost. Per molecule, methane is a much stronger greenhouse gas than is carbon dioxide—although it has much shorter residence times.

1.5. Take Away Ideas

- If not reversed, climate heating *will* destroy civilization.
- There are no negative feedback mechanisms, all physical feedbacks are positive (reinforcing).
- Without a multinational coordinated solution, in time, ocean rising will drown most of the world's major cities, because they have been built on ocean shorelines.

2. The Definition of and Role of *Energy Currencies*

In order to avoid burning fossil fuels, we must re-examine the roles of the energy system's components. Key to this is to recognize the *functional* roles, not only of energy *sources* and *services* but especially what I call energy ***currencies*** **—** fuels and electricity.

In order to appreciate the role of energy currencies, we need in front of us, stuck in our mind, a picture of the energy system's architecture.

If we want details, the architecture can become as complex as the architecture of our brains. But Albert Einstein reportedly advised, "*Everything should be made as simple as possible, but not simpler."* Figure 1 shows a

five-link architecture that I consider as simple as possible but not simpler. It identifies the system's *functional components*, not technologies. It should be easy for readers to mentally assign technologies within one or other of the functional components.

Fig. 1 – A five-Link Energy System Architecture—showing *functional* groupings
Рис. 1 – Архитектура энергетической системы с пятью звеньями, показывающая функциональные группировки

2.1. It's a Demand-Supply System

I recommend viewing the energy chain as a demand-supply system. Most engineers tend to follow energy flows. I did too. But after years thinking of the energy sources as where the system begins because that's from whence the energy flows, I realized it was better to think the other way round. So I reversed the order of components on the systemic diagram, to start from the left with the services people want, such as communication or transportation, and move to the right towards energy sources, such as coal or uranium.

Each service, let's take transportation, demands a service technology, such as an airplane.

In turn, the service technology, in our example an airplane, demands an appropriate currency (such as kerosene). And so on until we arrive at an energy source, for example bitumen in the ground.

Energy currencies lie at the center, the very heart, of this demand-supply chain. The role of a currency is to take energy harvested from an energy source, sometimes to transport it to where it's needed, but *always* to make it usable by the target service technology.

For instance, the currency electricity makes energy digestible by TV sets. Gasoline (petrol) makes energy digestible by spark ignition automobile engines.

Service technologies deliver the services we want—from driving our car to the market, to warming or cooling our home, to health care, to producing materials — and for powering free-range transportation such as air travel.

Many readers will believe they've always known and understood currencies—that I've merely given them a new name. Still, I ask readers to think again. Our climate problem is caused by carbon-containing **chemical currencies** (carbonaceous fuels), which, when burned, their carbon combines with atmospheric oxygen to form CO_2. Usually the CO_2 is dumped to the atmosphere.

Civilization must evolve towards energy systems that ***not only*** use non-C sources but ***also use non-C currencies.***

We have *all the non-CO_2 emitting sources we need.* They include hydraulic and nuclear power, wind, solar, tidal and so on.

And we have one non-C currency: electricity**.**

But we still need a non-carbon **chemical** currency — a chemical fuel that does not contain carbon. The best option is "neat"[†] hydrogen. Ammonia, NH_3, also meets the non-C requirement, but it suffers several other limitations.[‡]

2.2. The Reason Hydricity is Our Only Chance

One noun "hydricity" combines the twin currencies, hydrogen and electricity.

In order to eliminate all CO_2 emissions, hydricity must become our future. The following six-step rationale explains why:

1. Atmospheric CO_2 growth is bringing climate destabilization that, if not stopped, risks civilization's collapse.
2. To eliminate anthropogenic CO_2 emissions, we must restrict ourselves to using *both* non-carbon **sources** and non-carbon **currencies**.
3. There are many non-carbon sources including hydraulic power, wind, solar, geothermal, ocean tidal and wave power, and nuclear fission. (I consider fission the safest and most reliable, but it's hobbled today by misunderstanding and unrealistic fears.)
4. In contrast to the many non-carbon energy sources, there are only two non-carbon currencies, *electricity* and *hydrogen*. ***Together***, these two currencies can supply the full menu of energy services. Hydrogen cannot do it alone. Neither can electricity.
5. Hydrogen won't eliminate the use of electricity. Rather it will give electricity an exceedingly synergistic partner.
6. Therefore: *Anthropogenic CO_2 emissions can only be slowed by the extensive use of hydrogen, and can* ***only be stopped with the preeminence of non-fossil derived H_2 among chemical fuels.***

The title of this sub-section claimed, "… our ***only chance***." Such a declarative sentence might trouble some folks—not only for its apparent arrogance but also because we've been told we have many alternatives. But these many alternatives are all energy *sources*. Yet, in order to make a real contribution to stopping CO_2 emissions, any breakthrough energy source will need to

[†]English speakers say they are sipping vodka "neat" when it's not diluted with, say, orange juice or water.

[‡] Manufacturing ammonia requires first producing H_2 and then tying it to nitrogen, making it much heavier than H_2 for equivalent energy content. The overall process is $3H_2 + N_2 \rightarrow 2NH_3$. When weight reduction is a key strategy for efficient vehicle design, heavier ammonia is a disadvantage. One advantage NH_3 has over H_2 is that it is more easily liquefied. Still ammonia is noxious stuff. So why use NH_3 when we can use H_2.

feed a hydricity system. It must be able to make a fuel (currency) that can fly airplanes.

For more than thirty-five years, when asked to speak or advise people and organizations on energy systems and the future role of hydrogen, I have often challenged them to try to:

Identify an energy system, other than one dominated by hydricity manufactured by non-carbon emitting energy sources, which could be capable of providing all civilization's energy services, today and in the future, without emitting a drop of CO_2.

I've never received a realistic proposal. Still I'll be delighted if a reader of this article could identify a credible alternative.

2.3. Take Away Ideas

- Appreciating the role of energy currencies is key to identifying the essential role of hydrogen.
- But we also need electricity. Together we name these two currencies hydricity.
- Hydricity can energize the full menu of energy services civilization needs, or will ever want.

3. Some Features of Hydricity

3.1. Any Energy Source Can Be Harvested to Produce Hydrogen

We know any energy source can be harvested to produce electricity. And via electrolysis, electricity can always be used to split water and produce H_2. So it's clear any energy source can be harvested to produce hydrogen. Yet, there are often better ways than electrolysis.

Unlike other chemical currencies, to harvest hydrogen rather than say gasoline we need *both*:

- A material that contains hydrogen, from which to mine hydrogen.
- Energy to do the mining.

This is very different from other material currencies; for example, crude oil contains both the material and the energy that ends up in gasoline.

There are many ways to produce non-fossil derived hydrogen. Some use hydraulic or nuclear power. Some use sunlight directly. The latter should not surprise because, petunias and trees use photosynthesis to harvest hydrogen from water, H_2O, and carbon from atmospheric CO_2—allowing petunias and trees to grow, stay alive and have children.

3.2. Thoughtful People Still Miss-the-Point:

An article by James Bennet in *The Atlantic* "We Need an Energy Miracle" reports an interview with Bill Gates in which Gates says we need an energy miracle to solve the climate threat [5]. I expect the "hoped for miracle" Gates intends is an, as yet undiscovered, energy source.

In contrast, I believe the only miracle we need is for people to appreciate the role of energy currencies — and how that leads to the carbon-free hydricity siblings. As I hope to have explained, hydricity can take us to a civilization emitting zero greenhouse gases.

3.3. Misguided Faith in Renewable Sources

Even more misleading is the conventional *wishdom* that if we employ *only* renewable sources all will be well. *That's nonsense.*

It's nonsense, first, because many renewable sources such as biomass are not carbon free. Moreover, we've as yet failed to learn how to harvest renewables, like wind and sunlight, to manufacture C-free fuels for transportation without emitting CO_2. That's the role, when it finally becomes recognized, for hydrogen.

Moreover, it's very unlikely renewables alone can reliably and continuously provide the quantities of energy we will need either now or in the future.

Today when we look for non-CO_2 emitting currencies, the public and governments zoom to electricity. But electricity can't "fuel" aircraft — especially long-range aircraft — or, for that matter, many other transportation vehicles. So I'm back to reminding us that we need a non-CO_2 emitting fuel, which means H_2 — or often better yet liquid hydrogen, LH_2 in the case of aircraft [6].

4. Concluding Thoughts

4.1. Some Have Told Me the Word "Catastrophe" Is Too Strong

We face the prospect of sea level rise that can destroy some 90% of the world's largest cities (Mexico City escapes)—and the loss of many of the world's great food-producing deltas.

Anticipating the annihilation of their homelands, several island states are setting aside money to purchase continental land. We face massive and disruptive human migrations.

If these trends cannot be described as potentially "catastrophic," what could be?

4.2. If Hydricity is The Answer, Why Hasn't a Transition Started?

We lack a broad public understanding that hydricity is our only path to non-CO_2-emitting energy systems. Among government energy planners, there is little appreciation of the role of energy currencies. Government and industrial thinking is trapped in minor evolutions of today's fossil-fuelled world.

Industry and governments focus on business-as-usual with only gradual and minor trajectory changes. If government or industrial planners they think at all of hydricity, it falls outside their timeframe. So nothing significant has started.

We should appreciate and welcome hydricity as our energy system's end-state. And when planning innovation, we should be governed by the wisdom: ***"Keep the end in mind."***

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