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WHALES AND WHISKY BARRELS

In which tensions between attractors and barriers, the tugs and snags of change, are seen to steer energy system evolution.

It was a Sabbath afternoon in the waning summer of 1859. Pennsylvania blacksmith "Uncle Billy" Smith decided to use his day of rest for a stroll into the countryside. The stroll would take him past a well he had been drilling for Colonel Drake, a crazy fellow from the East. Drake, using his self-bequeathed rank of "colonel" to impress the locals, had commissioned Uncle Billy to drill a well outside Titusville—but not for water. Uncle Billy was drilling for *oil*.

The Colonel and his back-east financiers had decided to try drilling for illuminants, fuel for oil lamps, just like drilling for water. Everyone knew the scheme was preposterous—no one *drilled wells* for oil! Everyone knew whale oil was the best illuminant. But the high cost and limited supplies of whale oil restricted its use, keeping most living rooms in the dark. Kerosene and town gas were also used as illuminants and were somewhat less expensive. Kerosene, also called coal oil, was manufactured from the oily "drippings" oozing out from underground coal seams. Town gas, also called coal gas, was manufactured from coal in the town's "gas plants." But kerosene supplies were limited, and town gas tended to blow up houses and asphyxiate people—both in reality and in literature. The suicide that concludes Arthur Miller's *Death of a Salesman* was accomplished by town gas. (About half the heating value of town gas came from poisonous carbon monoxide. Today, natural gas contains no carbon monoxide.) So, many barriers blocked better lighting. Among these barriers, in the late 1800s, the high cost and limited supply of illuminants were the most important.

That is why Uncle Billy leapt with joy when he saw a sticky dark liquid floating atop the water in his well. Titusville boomed. Land prices rocketed. Frenzied drillers smacked holes into the ground hunting for "rock oil"—a name chosen to distinguish it from whale or coal oil. More and more rock oil wells gurgled. Soon supply exceeded demand and then, of course, rock oil prices plummeted.

Brandishing the weapon of innovation, Uncle Billy and his friends had smashed through the barrier of high-cost illuminants. Price, once a barrier, flipped to become an attractor pulling energy system evolution into an era of brighter living rooms. Not surprisingly, *innovation* unleashed this systemic evolution. Some form of innovation is always the trigger—this time it was the idea of driving holes into the ground rather than harpoons into whales.

But just as the price barrier was smashed, a new barrier jumped up in its place, like another duck in a shooting gallery. The next barrier was a shortage of whisky barrels in which to store and transport rock oil. For a short while, the price of barrels rose to be several times the price of the oil they contained. Some oil well drillers, trapped within a locally saturated market, began losing money. Suppliers of whisky barrels got ready for early retirement. Yet the momentum for change was there, and so, soon, would be the barrels.

Thinking about these events, watching the actors change while the theme repeats, my mind's eye jumps to our five-link energy system chain, slip-sliding along the arrow of time. Figure 1 represents this slip-sliding on a two-dimensional page. Still, for me, our slip-sliding chain is best seen with the colour and dynamics conjured in the mind's eye.

Sometimes the chain sweeps along quickly, as it did during the decades following Uncle Billy's Sabbath afternoon stroll. During those decades, the innovation of drilling for oil provided much more than oil: it provided an environment for a plethora of related innovations. Today we might call them "spinoff" innovations. Sometimes the chain gets snagged, often by just one link, or a corner of one link. If it's truly snagged, system development just about stops and the chain sits there, trembling, tensions building, as some links try to get on with their destiny, try to tug things into the future, but the snag holds back the show.

Curiously, in spite of much rhetoric about changing our present energy system, like our do-gooder talk about "renewable energy sources", today is pretty much a time of stuckness.[2] Most of this stuckness comes from our poor understanding of how the system works, of what parts are important and what less important, of what are real barriers and what are well-intentioned but useless slogans.

Snag versus tug imagery is a good way to think about energy system evolution—an evolution held back by *barriers* and pulled ahead by *attractors*.

Barriers and attractors may be grouped into *categories*.

First, there are *technical* barriers and attractors. A contemporary technical barrier is the difficulty of storing low-carbon fuels like natural gas and hydrogen onboard vehicles like cars and airplanes. On the other hand, an emerging technical attractor may soon be the fuelcell.[3] Fuelcells operate at high energy conversion efficiencies. Moreover, due to their modular construction—a bunch of plates that, in principle, can be cut to different shapes and stacked together in different sizes—fuelcells will be more suitable for mass-production and robot assembly than

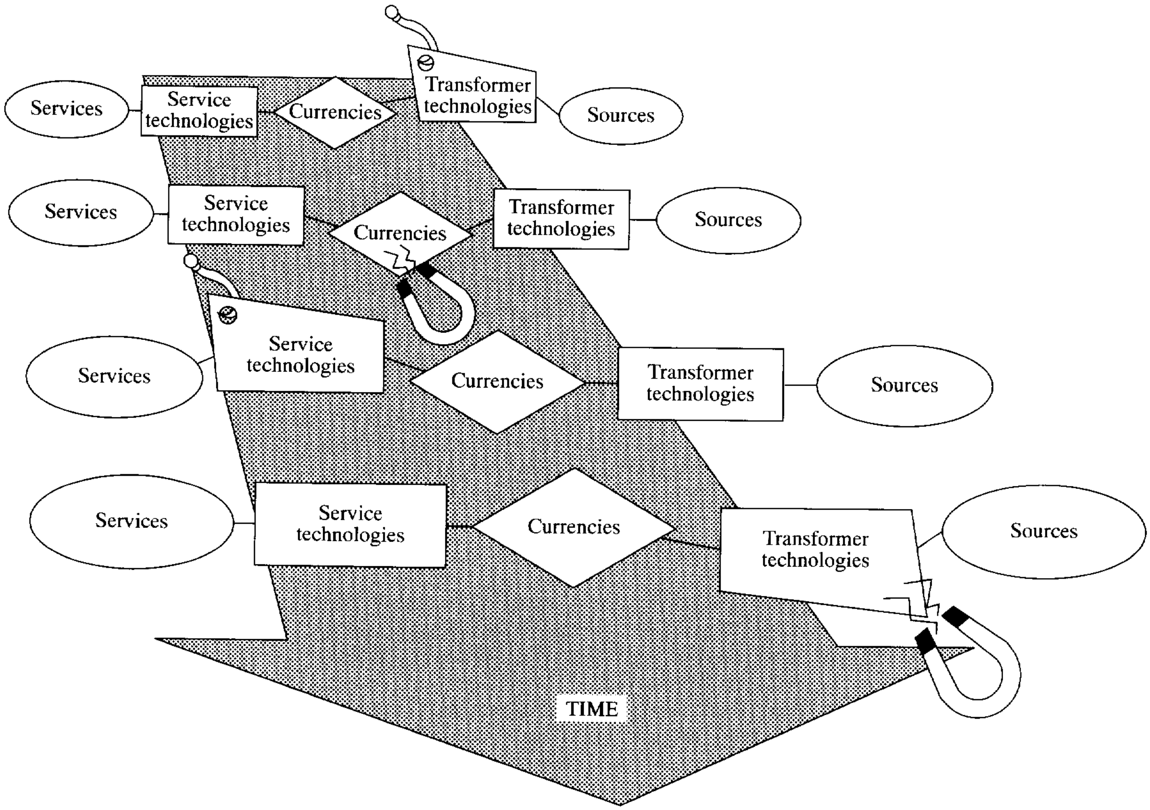

Fig. 1. Snag and tug imagery.

today's internal combustion engines which, by comparison, are less modular and require casting a different size engine block for each different engine power.

Next, there are *economic* barriers and attractors. A contemporary economic barrier is the high cost of liquefying natural gas and hydrogen—the most severe impediment to using these clean, efficient fuels in transportation applications. Both economic attractors and barriers can also be found in various fiscal policies like tax incentives, or monetary policies like interest rates. Together, these policies influence such things as the availability of capital and the time required to recoup investments in innovation. That is why monetary and fiscal policies can be either barriers or attractors. To illustrate, policies allowing long timelines to recoup investment will encourage innovation, while policies demanding short timelines discourage innovation.

There are also *cultural* barriers and attractors. The perception that we were running out of natural gas, prevalent in the late 1970s and early 1980s, is an example of a cultural barrier. Today's perception that nuclear energy is unacceptably dangerous—or somehow evil—is another cultural barrier, slowing what could become the greenest of energy sources. Turning to cultural attractors, examples include the public's desire for clean air and its growing awareness that atmospheric emissions may bring catastrophic climatic instabilities. Of course the significance of these challenges—especially the prospect of climate instabilities—will be both challenged on the one hand and dismissed on the other by vested interests. And that will set up a cultural barrier to compete with the original cultural attractor.

Fourth, there are *legislative* barriers and attractors. Past legislation that prevented natural gas from being used in electricity generation was a legislative barrier blocking the use of clean low-carbon fuels. Today's automobile emission laws constitute a legislative attractor, encouraging the use of these same low-carbon fuels.

Finally, there are *supply* barriers and attractors. They can be real or perceived, temporary or sustained. The whisky barrel shortage was a real, but temporary, supply barrier. Usually a perceived supply barrier has its roots in a cultural barrier.

In practice, barrier and attractor categories are usually coupled. It will be no surprise that supply barriers induce economic barriers. But there are many more complex linkages. The difficulty of storing low-carbon fuels onboard vehicles (our example of a technological barrier blocking the use of low-carbon fuels in transportation) could be

beaten if we reduced the high cost of liquefaction (our example of an economic barrier) which could, in turn, be achieved by technical breakthroughs in cryogenic refrigeration (which would then be a new technological attractor). Unless, of course, a cultural barrier arose in the public fear of low-temperature, cryogenic fuels, in which case we'd probably find ourselves with a legislative barrier forbidding their use—bringing us back to square one—blocked, once again, from employing low-carbon fuels in transportation.

Barrier-attractor examples are limitless, linked and liquid. Yet I believe it is the *concept* that is important, not a few examples like we just examined. The concept can be used as a tool, a methodology, a way of thinking—by investors hunting for business opportunities, by professors chasing research grants, or by legislators trying to stick together legislation that will lead to a better world rather than simply mollify special interests. Identifying barriers and attractors can be a powerful technique for sniffing out opportunities and dangers. And it is one more way of smelling land.[4]

For nations and corporations, the larger the barrier the larger the opportunity—and the more vigorous the systemic evolution when the barrier is breached. Barriers stop systemic evolution toward *quality*, *convenience*, *economic efficiency*, *energy efficiency* and *environmental gentility*. Removing a snag releases tensions that developed within the system while the barrier was in place. The power derived from the release of tensions is the power that speeds systemic change. Opportunities are always found within the turmoil of rapid change—just as kelp, fish and seals thrive in the turmoil of tidal estuaries.

During this turmoil, the people responsible for smashing a barrier have an inside track at getting rich, but it is not a guarantee. Having been pushed aside by the big guys, Colonel Drake died an impoverished, discouraged man.

For the small entrepreneur, inventor or investor, the mix of opportunity and danger comes in different proportions. It can be briefly exhilarating for small innovators when they find weapons to break the largest barriers. But soon the unleashed torrent whirls them this way and that, from one danger to another. Having triggered the next wave of systemic evolution, small entrepreneurs often don't have the resources to avoid drowning. That is why, if we were offering prudent advice, we might warn them away from the largest barriers or attractors. We might counsel them to seek out the small ones hidden deep within the system. Lesser barriers and attractors can yield colossal opportunities for little folks, with a lower level of kerfuffle and risk.

But we know that is not the way it works. Innovators are mutants—people seeing no bounds to their abilities or opportunities, willing to try anything no matter how audacious. And the truth is we need these innovators. We need them, using their ideas, bashing away at barriers until the barriers begin to leak—even if our sense of fair play is troubled when they pay the cabin boy's price.[4]

Introducing an attractor also accelerates systemic evolution, but seldom with the vigour of removing a barrier. That's because the system usually develops greater tensions when trying to break past a snag than it does when anticipating the tug of an attractor. Anticipating a tug is a tenuous kind of thing. Snags are more concrete—because they are easier to understand.

Anticipating the tug of an attractor is especially difficult for technical attractors. In the energy system, few businesses properly anticipate the effect of a technical attractor. When they try, most often they get it wrong, being either too starry-eyed or too dismissive. Getting it right requires understanding what the technical attractor does, being able to judge how "what it does" will impact systemic evolution, and mixing all this with entrepreneurial energy, management skill and a measure of luck. A tall order.

Industry is better at anticipating the effect of legislative attractors. If the captains of industry know anything, they know how new legislation will affect their business. Usually they have been trying to accelerate—or slow—proposed legislation for years. That is what they pay most of their lawyers, and all their lobbyists, to do.

The parable of whales and whisky barrels shows that when one barrier is smashed, new barriers pop up—like ducks in shooting galleries. That imagery dates me. Shooting galleries come from my memories loping and gawking through the Belleville Fall Fair as a young teenager, hands and face sticky with candy floss. Today, a teenager's imagery is more likely of the next video game monster flashing upon the screen just as the last monster explodes. Video game imagery might be better than shooting galleries, because video games can pop up both allies and enemies. When we translate this to energy systems, things become more subjective, since the next enemy (barrier) for some may be the next ally (opportunity) for others. That makes real life more fun than arcades. The clever can transform dangers into opportunities.

Now let's move beyond the saga that began with Uncle Billy's Sunday stroll. Soon Titusville had lots of whisky barrels. Illuminants became plentiful and comparatively cheap. Other innovators rode the coatails of abundant illuminants by inventing, manufacturing and distributing better lamps. Yet while cities and homes became brighter, lamps still produced soot, grime and fires. So the barrier to better illumination had shifted from high prices to a shortage of whisky barrels, and then to environmental degradation and risk to parlours, libraries and lives. Indeed,

risk of fire caused many libraries to refuse "artificial illumination". Gore Hall at Harvard College was one.

So a receptive world was waiting when, in 1882, with his banker by his side, Thomas Edison pushed a switch starting a generating station that fed electricity to his light bulbs. Once again innovation destroyed barriers, this time danger and dirt, and simultaneously introduced attractors, this time convenience and brighter rooms.

It was a pair of innovations that did the job: a new service technology, lightbulbs, and a new energy currency to feed lightbulbs, electricity.

Most people saw blessings in clean, safe, brighter illumination. A few saw dangers, and among these were the folks who owned oil companies. Then, in the 1890s, round the corner came a horseless carriage, its internal combustion engine burping, banging and needing gasoline. The horseless carriage pulled energy system evolution into the future. A future in which oil lost its illumination market, retained its lubrication market, and gained an entirely new market powering transportation. Several decades later, oil found yet another market as a feedstock for twentieth-century materials, like most of my sailboat, much of my car, and—well, look about you—just about everything from toothpaste tubes to machinery. So dangers for some are always opportunities for others. And when it's not just good luck, it is usually a sense of where systemic evolution is taking us that separates winners from losers.

We can also poke our nose into the near future. Earlier I said that one technological barrier holding back energy system evolution today is the lack of an inexpensive, convenient way to store low-carbon fuels like natural gas and hydrogen onboard cars, buses and airplanes, or any transportation vehicle. A breakthrough would allow us to carry fuels like natural gas onboard cars and airplanes as easily as we now carry gasoline, diesel, or Jet A. Using criteria of cleanliness, higher engine efficiency and lower engine maintenance, natural gas is a better fuel than today's conventional liquid fuels. That—and a price advantage[5]—is why, even with the onboard storage barrier still in place, natural gas-fuelled road-vehicles are capturing small market niches. If we can destroy the storage barrier, the resulting flood of innovation and investment will make natural gas the *staple* transportation fuel.

Finally let's venture into the deeper future. *Déjà vu* will characterize energy system evolution during the 21st century. Again, the evolution will centre about a pair of innovations. Again, the first will be a new service technology, this time fuelcells. Again, the second will be a new energy currency to feed the technology, this time hydrogen.

Like the innovation wave that began with electricity flowing through lightbulbs, the innovation wave that begins with hydrogen coursing through fuelcells will be just a beginning. A myriad of service technologies will then begin to enrich our lives, all using hydrogen, many unimagined before the new currency wave takes hold.

Can we imagine how unimagined these services are? I doubt it. Think back to the innovation wave spawned by electricity when new electric technologies spread outwards from their lightbulb nucleation site. Can you imagine how difficult it would have been for people in the 1890s to imagine cellular telephones or e-mail? Or to imagine sitting in their living room watching the assassin of a president being moved from one jail to another, and then watching, live on TV, while the assassin is himself assassinated. To have imagined those things in the 1890s would have been a lot more difficult than to have imagined simple, silly things like, say, a world that was a cube rather than a sphere.

When the hydrogen innovation wave begins expanding out from its nucleation sites early in the 21st century, it will mirror the earlier electricity wave by triggering a swarm of now unimagined service technologies. But because they are *truly* unimagined, we can't list them. We'll just have to wait. Whales and Whisky Barrels is a tale of oil—different kinds of oil, different ways to get it, different barriers and attractors to its use, and the different services oil came to provide. The tale began with illuminants so expensive that few people could afford good lighting. Then prices dropped. For a brief time some people had so much of the new illuminant that there were not enough barrels in which to store the stuff. Soon we had lots of barrels, lots of illuminants and lots of lamps.

Then, as if on cue, the next barrier appeared—born, if you like, from "too much of a good thing". All these lamps brought too much soot, grime and danger. If it happened today, consultants might say the lamps caused a "severe deterioration of living room air quality" and an "unacceptably high risk of fire." So, when lightbulbs fed by electricity came over the time-horizon, they found a welcoming world. Lightbulbs brought cleaner, safer and better illumination, and kicked oil-fed lamps out of kitchens, dining rooms and parlours. Oil lamps were destined for trash heaps and, later, antique shops. But oil itself was rescued by a new role, supplying a new service. That service was transportation.

Now, a century later, too much of a good thing may again spell the doom of today's oil-fed service, because oil-powered transportation is bringing environmental damage to much larger rooms, risks to a much larger home. The rooms are our cities. The home is the biosphere of planet Earth.

Again, an innovation pair is getting ready to deliver the troubled service, getting ready to extract civilization's tail from this crack. Again, the innovation pair comes in the form of a new technology and a new currency to feed the technology. The technology is the fuelcell. The currency is hydrogen. Working together they will provide cleaner, safer and better transportation. In time, they will push oil-fed transportation from our rooms. Later they will chase it out of our home.

The eighth in a series of articles by

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1. Well recounted by Daniel Yergin in *The Prize*, Simon and Schuster (1991).
2. What I mean by "stuckness" is clear from context. For those wanting a beautiful discussion of stuckness, I recommend Robert M. Persig's *Zen and the Art of Motorcycle Maintenance*, Robert M. Morrow and Co. (1974).
3. Normally we call this technology a "fuel cell." But when a noun made up of two nouns comes into general use, English usage often first hyphenates and then later welds together the two words, like home work, home-work and homework. If, *in addition*, the double-noun is especially awkward in frequent use, like hydrogen fuelled fuel cell, I believe there is good reason to accelerate this linguistic process.
4. D. S. Scott, Smelling Land. *Int. J. Hydrogen Energy* **19**(1) (1994).
5. Today's price advantage results, primarily, from low or zero taxes compared with conventional fuels. Expect higher taxes to appear if a significant proportion of the road-vehicle populaiton is fuelled by natural gas.