Energy Transitions – Strategies for Selecting Amongst a Plethora of Technology Choices

Greg Leveille, December 2022

Executive Summary

- During large-scale, crisis-spurred, technological transitions, numerous potential solutions will be identified, almost all of which will be championed by strong advocates expounding "compelling" investment theses.
- Given human's shortcomings at quantitatively assessing risk and uncertainty, and investors' fear of missing out on breakthroughs during times of transition, many potential solutions will attract funding, with the "winners" of the auction-like process that matches investors with non-in-house-developed solutions being those investors that most-highly value a particular solution.
- Because funding conveys legitimacy, momentum often builds around solutions even before results are obtained that would confirm or refute critical aspects of investment theses.
- Once an investor commits to pursuing a particular solution or suite of solutions, they often stop assessing other opportunities – thereby developing blind spots as to which solution(s) are likely to win the race to solve the crisis that created the need for a transition to occur.
- Because innovation is usually a highly iterative process, one where experimental results often redirect efforts towards new, more promising pathways, opportunities for which results can be obtained quickly and at low cost will be advantaged over ones where experimentation is slow and costly.
- Cost to experiment, speed of experimentation, the number of players pursuing an opportunity, and the degree of collaboration between players are therefore crucial innovation success factors – factors that should be given far more weight than they traditionally are in making and updating technology development investment choices.

Insights from the Early 21st Century O&G Crisis that Created the Need for a Transition

For most of the 20th century, hydrocarbons were cheap to produce and consume, enormously abundant, and especially for oil, easy to store and transport.

Cheap, reliable, and abundant – a winning combination when it comes to energy.

It is therefore not surprising that there was an enormous sense of crisis at the start of the 21st century when, unlike with prior supply related disruptions that were caused by human-induced factors, factors that could at least theoretically be reversed quickly if cartels could be broken or wars won, this time, it was nearly universally believed that **the world was running out of oil**.

It is therefore not hard to see why leaders of hydrocarbon importing nations and the oil & gas industry foresaw the need for a transition, either to other forms of energy (which is why America rapidly scaled up its use of biofuels shortly after the start of the 21st century) or to other not-yet-commercial sources of oil and natural gas.

The oil & gas industry's response to this looming crisis was multi-pronged. It included not only efforts to **identify, commercialize, and scale new sources of economically producible hydrocarbons**, which is the topic this paper focuses upon, but also efforts to:

- Apply technology to extend the life of super-giant onshore and shallow water conventional oil fields and onshore heavy oil fields, the majority of which are in politically unstable or unfriendly countries (e.g., Russia, Iran, Venezuela, Libya, Kuwait, Iraq, Nigeria).
- Rapidly scale up capacity to export LNG from "stranded" super-giant gas fields in Qatar and Australia to markets in the U.S., Europe, and east Asia where demand for natural gas either already far exceeded local production or was expected to do so soon.
- Find additional conventional resources in deep water basins around the planet, with deep water at the time being where exploration was focused because onshore and shallow-water targets had been almost entirely picked over during the 20th century.

Interestingly, and to the credit of the oil industry, whereas all three of the bullet-pointed efforts noted above added production that helped fill the expected supply/demand gap, with the benefit of hindsight, it is obvious that they alone would not have been sufficient to close the gap, which is why industry investments to identify, commercialize and scale new sources of economically producible hydrocarbons were so important.

So, what types of new opportunities did industry invest in? As shown in Figure 1, industry pursued a diverse suite of technologies and asset types, some of which represented traditional targets in nearly impossible to operate in environments (e.g., ice-covered arctic seas), others that represented ways to convert super-giant natural gas deposits far from major markets into liquid hydrocarbons, and still others that required finding ways to access hydrocarbons that were literally locked in rocks (e.g., oil shale, gas hydrates, and unconventional reservoirs).

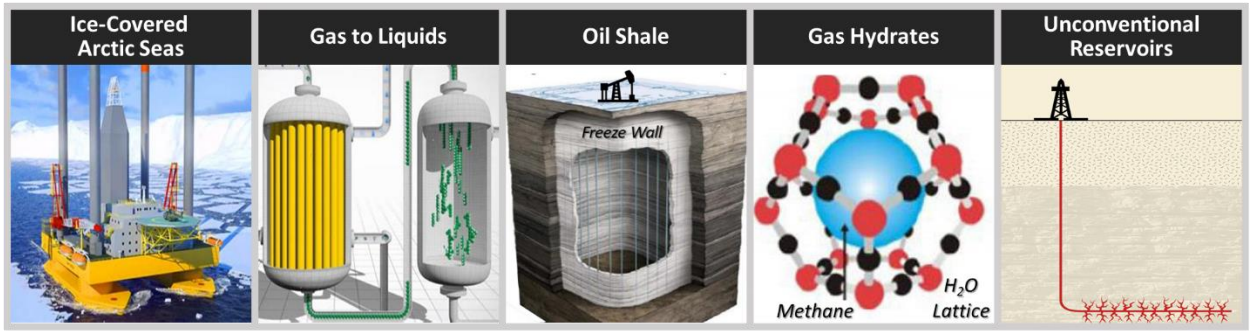

Figure 1. Not-yet-commercial technologies and asset types pursued by the oi industry and governments shortly after the start of the 21st century to enable a transition away from onshore and shallow-water fields – fields that could no longer meet growing global demand.

And while with hindsight it is clear that unconventional reservoirs were the best bet by far amongst the many new sources of hydrocarbons available for companies and governments to pursue, this was not at all obvious at the time, as evidenced by the fact that the oil majors (i.e., ExxonMobil, Shell, Chevron, BP, and Total) and most other large international operators invested tens of billions of dollars pursuing the first four opportunities shown in Figure 1, with little spent on unconventional reservoirs, and kept investing in these opportunities for nearly a decade after a breakthrough was achieved in commercializing production from unconventionals.

Observations, Insights, and Lessons Learned

Given the extraordinary magnitude of the oil industry's investments to identify, commercialize, and scale new sources of economically producible hydrocarbons between 2000 and 2015, it is worth investigating both: i) factors that enabled spectacular success to be achieved in unconventional reservoirs, and ii) why the world's largest oil & gas companies – companies that had access to much of the industry's top talent and enormous amounts of capital – failed in their efforts to perfect technologies to commercialize production from ice-covered portions of the offshore Arctic, oil shale, gas hydrate deposits, and gas-to-liquids conversion.

The observations and insights that follow are based upon: i) the personal experiences of the author while leading ConocoPhillips' U.S. Lower 48 unconventional reservoirs exploration efforts between 2006 and 2009 when the company assembled large acreage positions in the Eagle Ford and Bakken, and leading all or portions of ConocoPhillips' technology programs between 2011 and 2021, ii) knowledge gained from interactions with colleagues in and outside of ConocoPhillips over the past four decades, and iii) extensive reading about innovation related topics.

General innovation-related observations and insights that are important for setting the stage for discussion about efforts by oil companies and governments to identify, commercialize, and scale new sources of economically producible hydrocarbons at the start of the 21st century include:

- Innovation at scale is almost always a highly iterative process – a process that benefits from the incorporation of learnings from both successful and failed "experiments". Because of this, opportunities that can be tested quickly and cheaply, and then tested again and again quickly and cheaply as insights from prior experiments are incorporated, are greatly advantaged over opportunities where experiments are expensive and take a long time to execute.
- Given that no one individual or organization is all knowing when it comes to attempting to identify, commercialize, and scale new technologies, having many "players" with diverse backgrounds pursuing an opportunity increases the probability of success.
- The degree to which learnings are shared between players pursuing an opportunity has a significant impact on the pace of progress and the ultimate chance of success, with "innovation ecosystems" in which there are many players and results are shared openly being strongly advantaged over closed ecosystems with few players.
- People's ability to accurately quantify the probability of success and size of the prize associated with new, technically complex opportunities is poor. Humans also struggle with accurately updating probabilities as new information becomes available.
- People are better at qualitatively ranking like-kind opportunities one-against-another.

Given these realities, it is instructive to qualitatively rank the new sources of hydrocarbons that were being pursued shortly after the turn of the century against factors relating to cost and speed of experimentation, the number of players involved, and the degree of collaboration between players, which has been done in Figure 2 below.

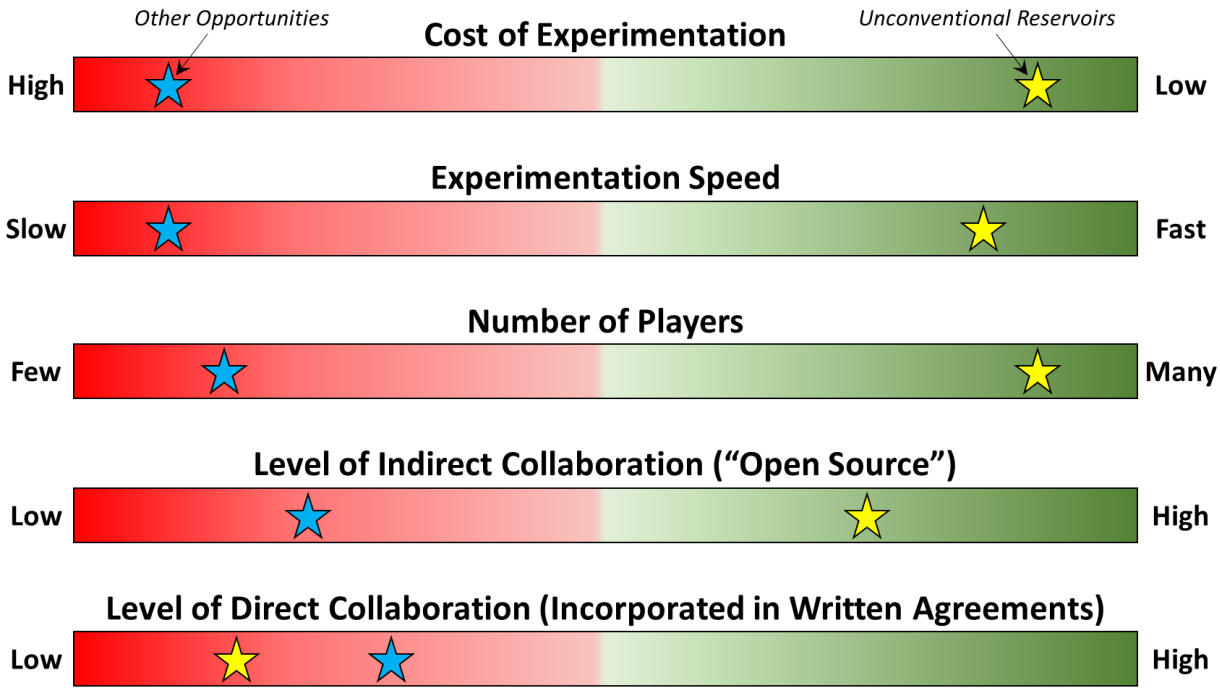

Figure 2. A slider bar representation of the innovation success factors noted in the text, with circumstances that are highly favorable for delivering successful outcomes being on the right side of the slider bars and unfavorable circumstances on the left. The approximate relative position of unconventional reservoirs and the other four opportunities that garnered significant funding from oil companies and governments during the 2000 to 2015 timeframe (arctic offshore; GTL; oil shale; gas hydrates) are shown by yellow stars for unconventionals and blue stars for the remaining four categories, which were grouped together because they have broadly similar characteristics. Please note that the "level of collaboration" factor has been broken into two subcategories to allow differences in approaches to be articulated in greater detail in the body of this paper. Please also note that the positioning of the stars are based upon the author's knowledge and perceptions, and the author realizes that other people may place them differently.

What stands out from this exercise is that unconventional reservoirs were advantaged in almost all the measures plotted.

And while it was not predestined that unconventional reservoirs would beat out the opportunities being pursued by major oil & gas companies, unconventionals reservoirs were hugely advantaged by the fact that each full-scale "experimentation cycle" cost relatively little to execute (a few hundred thousand to a few million dollars) and provided feedback extremely quickly (in a few weeks to a few months), whereas experimentation cycles for the opportunities pursued by the majors costs tens to hundreds of millions to billions of dollars each and took so long to complete that no opportunity finished more than one experimentation cycle between

2000 and 2015, and many were shut down before even one experiment could be completed (e.g., oil shale).

Furthermore, it is worth noting that the innovation success factors that were instrumental in allowing unconventional reservoirs to achieve its "breakthrough moment" were also crucial for allowing them to scale quickly, with scaling of the magnitude that enabled the U.S. to double its hydrocarbon production in fifteen years having been enabled by continuous, rapid, low-cost, open-source experimentation that drove down industry average cost of supply to the point that unconventionals reservoirs rapidly garnered a disproportionate share of available industry funding.

Given that a similarly spectacular scaling of potential solutions will be required if humankind is to achieve a successful outcome to the climate-change-related energy transition that is currently underway, it is herein suggested that it is worth considering how the plethora of potential low-carbon energy technologies that are attracting investment might be prioritized using the "innovation success criteria" outlined in this paper, which is the topic discussed in the next section.

Applicability of Insights Gained and Lessons Learned to "*The Energy Transition*"

Observations that suggest there is a high degree of applicability of the oil & gas industry's experiences with navigating the transition it faced at the start of the 21st century to *The Energy Transition* include:

- When it comes to delivering solutions to technologically complex challenges, the ability to quickly execute low-cost experiments and learn from others are invaluable traits regardless of whether the challenge resides in the realm of oil & gas development or is much broader in scope.
- Human biases, blind spots, and decision-traps are technology challenge agnostic, being elements that negatively impact nearly every significant technology development related endeavor.
- As with the oil & gas industry's efforts to commercialize new sources of hydrocarbons, numerous potential solutions to *The Energy Transition* have been identified (e.g., nuclear fusion; advanced, large to small-scale nuclear fission; hydrogen; CCUS; geothermal energy; offshore wind; and advanced battery technologies), almost all of which are being championed by strong advocates expounding "compelling" investment theses.

It is therefore likely that, i) the "innovation success factors" that helped unconventional reservoirs win the race to supply new sources of hydrocarbons will be important in determining the outcome of the competition between technologies to deliver "low-carbon" energy solutions that is currently underway, and ii) these factors will be underappreciated by many of the players involved in the competition.

Regrettably, the author does not have deep knowledgeable about enough of the low-carbon energy solutions being pursued to opine authoritatively upon which ones, if any, are positioned to achieve a breakthrough of similar scale as unconventional reservoirs did – a breakthrough so

large that it made pursuit of other solutions pointless, and which ones are more akin to the solutions that major oil & gas companies pursued unsuccessfully at great cost.

It is however believed that technology leaders responsible for selecting between potential low-carbon energy solutions will have enough information to incorporate these insights and lessons learned into their evaluations, with an example of how doing so might beneficially influence thinking about one specific potential solution being provided in the next section.

Enhanced Geothermal Systems (EGS) Example

Geothermal energy solutions are an interesting opportunity when it comes to cost and speed of experimentation, the number of players likely to be involved, and the ability to learn from others.

Geothermal solutions involving the harvesting of heat by flowing a fluid between wells through hydraulically created fractures are particularly intriguing given a player's ability to leverage knowledge gained not only from their own and others geothermal experiments, but also from the extensive body of knowledge derived since 2005 from the hundreds of billions of dollars invested in unconventional reservoir developments.

In fact, as is shown in Figure 3, it is the delta between the approaches that have been used to date to exploit geothermal energy sources and the applicable technological capabilities developed for extracting hydrocarbons from unconventional reservoirs that make this opportunity potentially exciting.

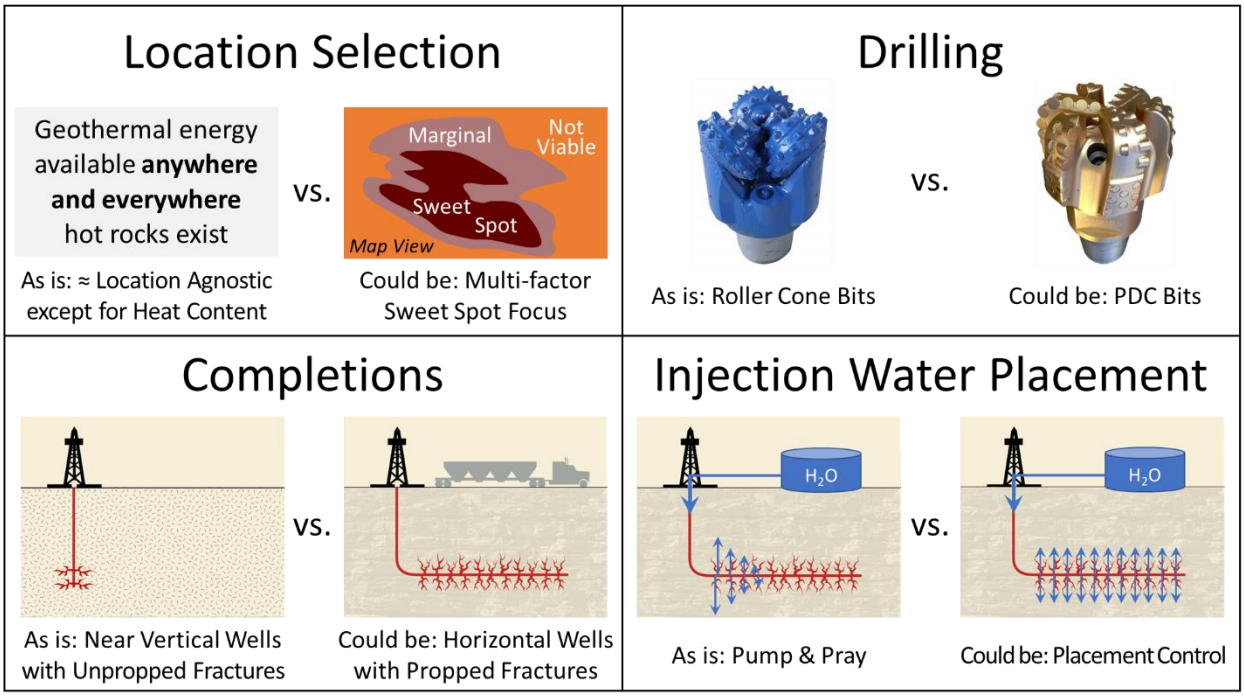

Figure 3. A comparison of past practices utilized for extracting geothermal energy using induced fractures with state-of-the-art practices used by the oil & gas industry for developing unconventional reservoirs, and in the case of injection water placement, improving recovery from conventional oil fields.

By way of building out the story encapsulated in Figure 3, it is worth noting the following:

- As was the case in the early days of unconventional reservoir exploration when many players invoked a "statistical drilling" paradigm to explain differences in well results within "play fairways", and therefore failed to appreciate that the interaction of several key geologic factors controlled the location of "sweet spots", geothermal exploration seems to overemphasize heat content and underappreciate other geologic factors, especially factors related to rock type and stress conditions, although to be fair to the geothermal industry, this is undoubtedly due in large part to a paucity of subsurface data since few wells have been drilled very far into "basement rock" formations, and even fewer wells have gathered significant geologic data in such settings.
- Recent results of experiments performed to determine whether PDC bits could improve drilling speeds in "hard rocks" have been encouraging, with PDC bits having significantly outperformed the rock bits traditionally used to drill "hard rock" geothermal wells with regards to both rate of penetration and bit life during trials performed at the FORGE project in Utah.
- As in the early days with unconventional reservoirs, completion design is the area most ripe for improvement, with almost all geothermal wells that have been drilled to date having been drilled vertically and completed open hole, and for those geothermal wells that have been fracture stimulated, hydraulic fracturing having generally been carried out without the use of proppant.
- The use of vertical or near-vertical wells to form injector / producer geothermal well pairs makes achieving hydraulic connections between paired wells extremely difficult given the limited width of fracture zones nucleated from perforations in vertical to near-vertical wells. Switching to horizontal or near-horizontal well designs should therefore greatly improve the likelihood and quality of connectivity.
- When it comes to the evolution of unconventional reservoir well designs, no element has undergone more rapid and greater changes than the modifications that have occurred around well completion methods. And while it is difficult to prejudge what approach might work best in creating complex, high-flow-rate pathways between injector / producer pairs in EGS reservoirs, much improvement is seemingly possible.
- As is well documented from waterfloods and other types of injection-related improved recovery techniques used in oil reservoirs, managing the placement of injectants to ensure uniform flow through the reservoir and prevention of short-circuiting is crucial for maximizing recovery. This will also be critical for geothermal developments where the heat recovery mechanism relies on flowing fluid between wells, with the "pump & pray" methods currently being utilized making this an element ripe for technology transfer and/or development.

Strategies for Selecting Amongst a Plethora of Technology Choices – Closing Thoughts

It has often been claimed that novel innovations are far more likely to be produced by small, entrepreneurial companies or individual entrepreneurs than by large, established firms.

And at first glance, the story of the unconventional reservoir revolution certainly seems to fit with this hypothesis, with the viability of extracting hydrocarbons at commercial rates from ultra-low permeability reservoirs having been proven up by George Mitchell, who earned a degree in petroleum engineering with an emphasis in geology from Texas A&M university in 1940, formed an independent oil & gas company while serving in the Army Corps of Engineers during World War II, and throughout a nearly six-decade long career in the oil & gas industry distinguished himself as an innovator par excellence – an innovator who, starting in 1981, experimented for over twenty years with methods to extract gas at commercial rates from the Barnett Shale before achieving the initial completion and well design breakthroughs that would peak the curiosity of numerous other companies, drawing in at first other independent operators, and eventually companies of larger and larger scale as the search for unconventional reservoir "sweet spots" rapidly expanded from the Barnett Shale to other "shale gas" plays, and eventually targeted unconventional oil reservoirs as well.

However, an alternative explanation that could be drawn from the broader history of how unconventional reservoirs beat out novel technologies being pursued by major oil & gas companies during the same time frame would be that **knowledge gained from experimentation is the most important factor in the achievement of breakthroughs**, with the size of the companies involved being of secondary importance.

That this is a viable explanation is supported by the following observations:

- The opportunities pursued by major oil & gas companies were no less novel than the idea of extracting hydrocarbons from shale, with two of the opportunities – gas hydrates and oil shale – being strikingly similar to unconventional reservoirs regarding the crux of the challenge that needed to be overcome in that they required the development of technologies to extract hydrocarbons that were like shale gas, essentially "locked in rocks" (i.e., the hydrocarbons were for all intent and purposes immovable using existing subsurface extraction technologies).
- For oil shale, both Chevron and ExxonMobil conceived of innovative extraction methods that involved hydraulic fracturing, which, as is now obvious, was one of the key technologies that enabled the unconventional reservoir revolution.
- The amount of monetary and human resources committed by the majors to develop solutions to the challenges inherent in the opportunities they pursued were far greater in absolute terms than those committed by Mitchell Energy and other early movers in unconventional reservoirs.

- And the level of perseverance shown by the majors was on par with that of independent oil & gas companies pursuing unconventional reservoirs, with the timelines of the technology development projects the majors pursued almost all exceeding a decade in duration, and many of the projects requiring significant regulatory and political hurdles to have been overcome.

It is therefore believed that the correct explanation for why unconventional reservoirs were successful and the other opportunities failed has mostly to do with the innovation success factors outlined in this paper, with these factors, in the final analysis, being crucial for the attainment of knowledge – knowledge that can come from either one's own experiments or those performed by other players – knowledge that can help an innovator by redirecting their efforts towards new, more promising pathways related to an opportunity they are pursuing or by encouraging them to terminate efforts that seem far less promising than initially believed, thereby freeing up resources to pursue other opportunities.

These factors should thus be given greater weight than they seemingly traditionally are in making and updating technology development investment choices, with this being true both for oil & gas related technologies and the plethora of technologies currently being pursued to help achieve *The Energy Transition* – a transition required to limit climate change impacts related to the rapid buildup of greenhouse gases in the atmosphere and oceans.

Finally, it is worth noting that while small companies and individual entrepreneurs naturally have to focus on rapid, low-cost experimentation and learning from other players because they have limited resources to support more expansive efforts, there is nothing preventing large companies from prioritizing investments with similar characteristics, except perhaps for the (mistaken) belief that for a technology development project to have an impact on a large company's bottom line, it must have mega-project-like characteristics.

Unfortunately for most of the oil industry's major companies, the size of the unconventional reservoir prize was initially seen as being too small to be of interest, likely because they focused on well-scale rather than play-scale resource and economic numbers, condemning all of them, except for Chevron, who had large, legacy mineral interest holdings in the Permian Basin, to have to pursue "play entry" primarily via acquisitions rather than leasing, which, while it can be a viable means to build a position, is usually expensive once industry participants realize that a breakthrough of enormous size has been achieved.

It is therefore worthwhile for large companies to avoid falling into the trap of ignoring or underweighting what might appear at first glance to be "small or niche company" opportunities <u>if</u> the opportunities allow for rapid, low-cost experimentation and could represent a substantial business when considered in whole rather than in part.

Note to Readers

These “Cliff Notes” are meant to accompany a much more substantial white paper on the same subject. The white paper contains considerably more detail plus figures, references, and acknowledgements. Please refer to the white paper before contacting the author with questions, observations, builds, or concerns.