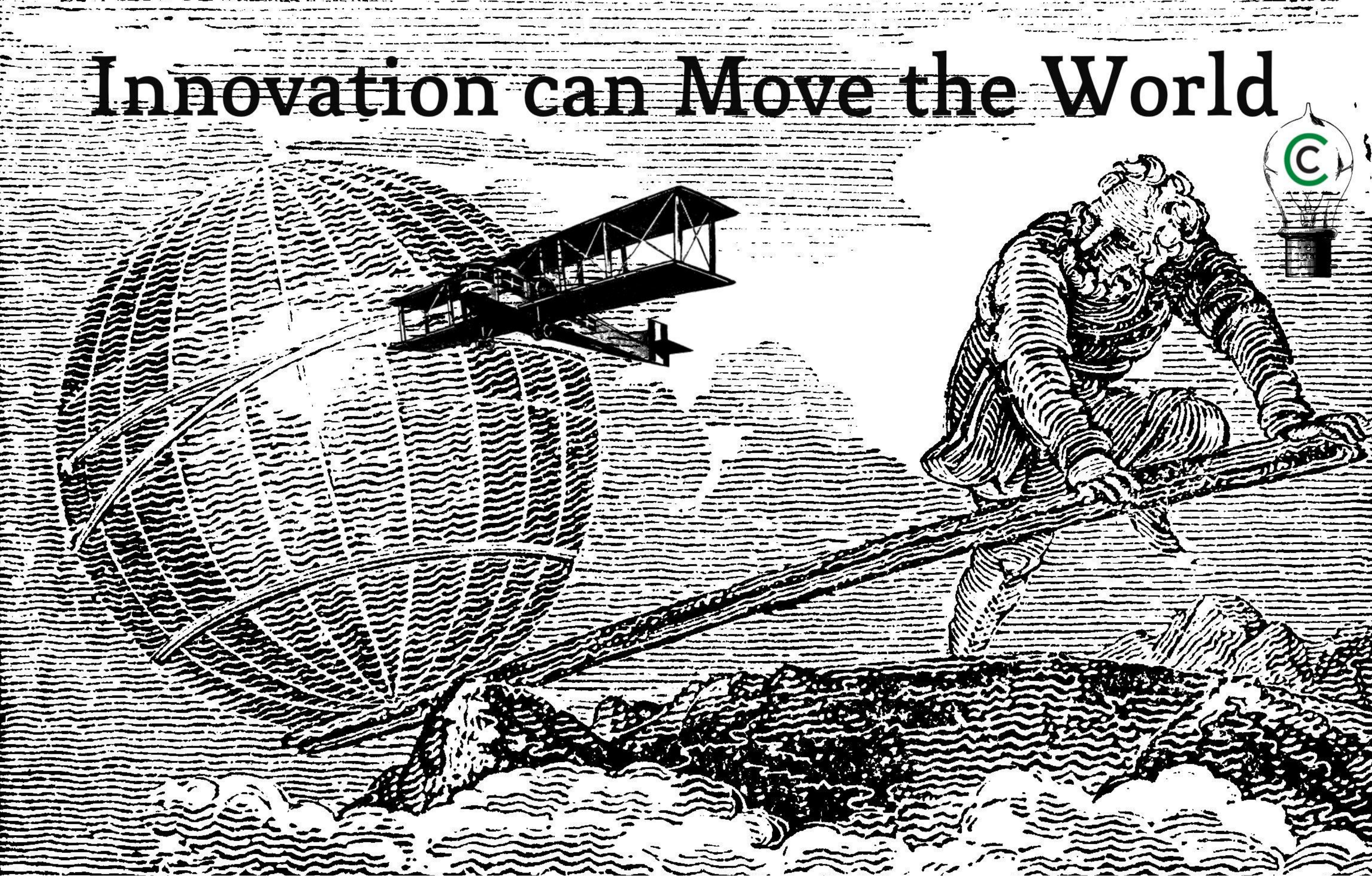

The Pyrolysis 1000

This report provides aggregate data on the commercial status of torrefaction (biocoal), slow pyrolysis (biochar), fast pyrolysis (pyrolysis oil/biochar), hydrothermal (hydrochar/biocrude), and biomass gasification (producer gas/biochar) ventures.

Commercializing Innovation

SIXTH ELEMENT SUSTAINABLE MANAGEMENT

FOR PUBLIC CIRCULATION

Prepared by: Gerald Kutney

Bio of the Author:

Dr. Kutney, Ph.D. in chemistry, has participated in all aspects of innovation and technology commercialization - especially related to torrefaction, pyrolysis, biochar, and biomass gasification - from the research laboratory to patents to marketing to the executive suite. With two decades of executive experience in technology commercialization with global corporations and entrepreneurial enterprises, he brings the innovation of research and technology development, the financial discipline of big business, and the spirit of entrepreneurship to start-ups and early-stage companies. He has extensive C-level experience, including strategic, operational, business development, and administration leadership, business and financial planning and analysis, financing strategies, techno-commercial evaluations and feasibility studies.

Bioenergy and Biofuels

- Director of Emerging Technologies and lead consultant in forestry bioenergy for the world's largest bioenergy and biofuels consulting group (Lee Enterprises Consulting)
- Director of Biochar Ontario
- Founded the LinkedIn group, *Bioenergy Projects & Ventures*
- Executive of a biorefining group (bark boiler and CHP/IPP facilities; the largest cellulosic ethanol business in North America; and bioproducts business with operations in Canada and France) of a major forest products company
- Executive of a biomass processing business in Canada
- Executive of a pyrolysis venture with pilot facilities in Canada and South Africa
- Authored over a dozen papers on pyrolysis presented at major bioenergy conferences (including the IEA Bioenergy, International Bioenergy Conference, and CanBio)
- Authored technical papers: *Biomass Pyrolysis Spectrum* and *The State of Pyrolysis in Canada*
- Authored a study on the global pyrolysis industry for the National Research Council Canada
- Authored a study on the commercial status of wood-to-(drop-in) fuels for a European client
- Mentored and edited the business plans for a biomass pellet venture in the U.S.
- Prepared feasibility studies and business/financial plans for First Nation's forestry ventures in Canada
- Audited the commercial preparedness of a pyrolysis venture for an IPO in Canada
- Member of the expert panel on international standards for solid biofuels (wood/biomass pellets, torrefied pellets and biochar briquettes) for ISO (TC 238)
- Member of the expert panel on Canadian standards for solid biofuels for CSA

Climate Change and Policy Development

- Authored the peer-reviewed book *Carbon Politics and the Failure of the Kyoto Protocol*, which examines the policy challenges for addressing climate change
- Adjunct Professor & Part-time Instructor on fourth-year/graduate course on Climate Change, University of Northern British Columbia – Environmental Science

Entrepreneurship and New Ventures

- Managing Director of own consulting venture
- President of an emerging-technology venture
- Chief Operating Officer with a new-technology venture
- Approved consultant with the Business Development Bank of Canada (BDC, Entrepreneurs first)
- MBA mentor & Start-up Garage mentor at the University of Ottawa
- Entrepreneur mentor with Invest Ottawa

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The Pyrolysis 1000

INTRODUCTION

The dominant renewable fuels are produced from biomass. These biofuels include a variety of technologies to treat biomass, which I have grouped into four major types:

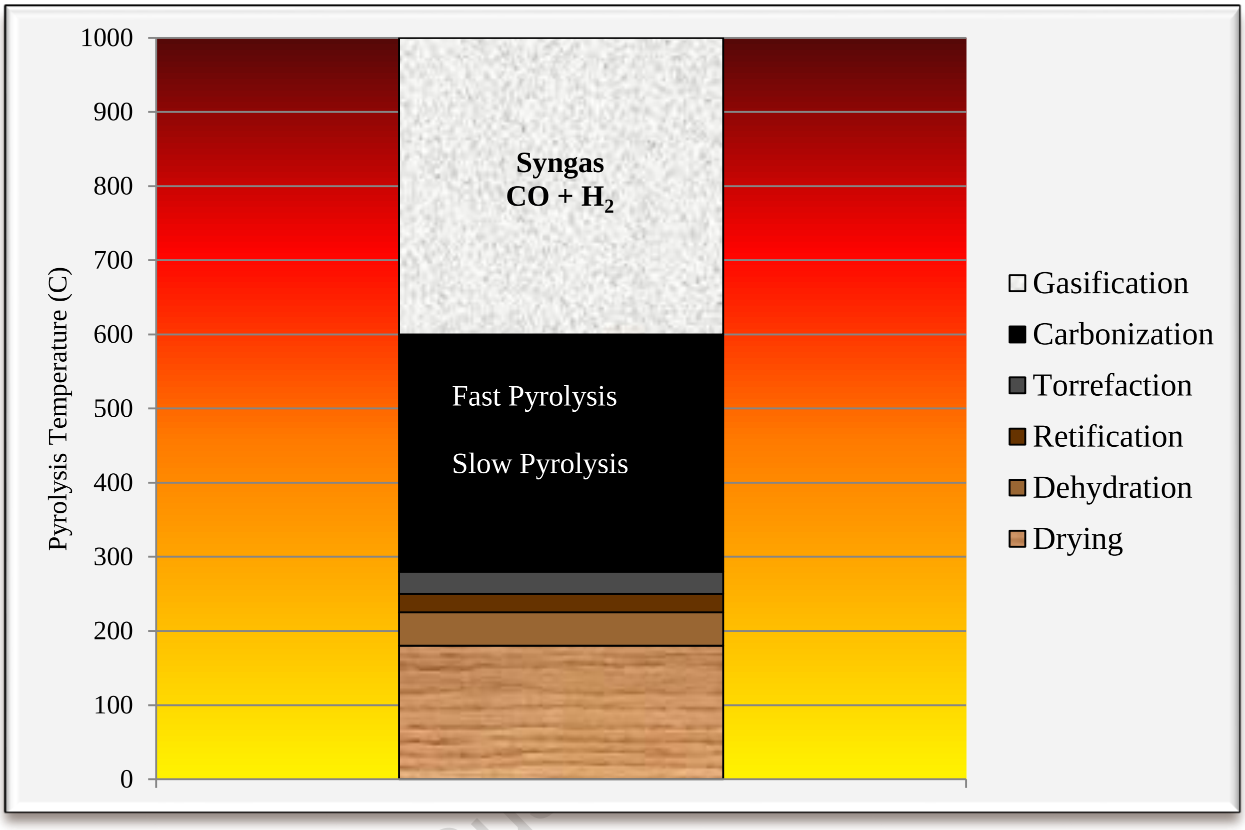
1. Mechanical: traditional routes for treating forestry biomass such as chipping and grinding; greater densification takes place by pelletizing the biomass.
2. Chemical: the best known of these processes is the transesterification of vegetable oils into biodiesel.
3. Biochemical: the leading biofuel, fuel ethanol, is produced from sugar or starch fermentation; another biochemical process is the production of biogas (biomethane) under anaerobic conditions.
4. Thermochemical: combustion converts biomass into energy, while pyrolysis (outlined in red in the table) converts biomass into fuel. The latter process not only yields greater energy density than mechanical treatment but the properties are chemically and physically more similar to fossil fuels than the original biomass. A related process is gasification which yields producer gas/syngas: a platform technology for the production of a variety of liquid biofuels, through the Fischer-Tropsch (FT) chemical process.

Biofuel Technologies

Mechanical	Chemical	Biochemical	Thermochemical
Chipping	Biodiesel	Anaerobic Digestion	Combustion
Grinding	Syngas-FT	Biogas (biomethane)	Torrefaction (biocoal)
Cubing/ Densification	Cellulosic Ethanol	Cellulosic Ethanol	Slow Pyrolysis (biochar)
Pelletization		Fermentation (ethanol/butanol)	Steam Thermal (black pellets)
			Fast Pyrolysis (pyrolysis oil/biochar)
			Hydrothermal (biocrude/hydrochar)
			Gasification (producer gas/biochar)

Chipping, grinding, pelletization, biodiesel, anaerobic digestion, biogas, fermentation ethanol, and combustion are established industries, with facilities that have been successfully operated for a number of years. The others fall within the emerging class and have not been fully proven on a commercial scale, at least not to the extent of the others. A major group of emerging biofuels are the pyrolysis-type, which are highlighted in a red box in the table under the thermochemical category. The common feature of pyrolysis is that the biomass undergoes a heating process in a low oxygen environment, which includes: torrefaction (biocoal), slow pyrolysis (biochar), steam thermal (black pellets), fast pyrolysis (pyrolysis oil/biochar), hydrothermal (biocrude/hydrochar), and biomass gasification (producer gas/biochar). These pyrolysis processes are the vanguard of leading-edge biofuel development.

The Stages of Pyrolysis of Biomass



Sixth Element Sustainable Management maintains a comprehensive global database of biomass pyrolysis technology developers and ventures ("Pyrolysis Venture Database"). Relevant references to the companies and their projects are imbedded in the inventory of firms. Also included in the Pyrolysis Venture Database is an appraisal of their stage of commercial development. To celebrate the 1000th entry, an aggregate data study is presented in this report.

The Pyrolysis Venture Database is important for investors and entrepreneurs alike. The information is a valuable resource for vetting the investment choices and assessing the competitive position of pyrolysis ventures. Ventures often claim to have the best technology, but have no evidence to back it up. The Pyrolysis Venture Database is a guide to where a venture stands relative to its peers and to the best-in-class technology providers.

METHODOLOGY

The scope of this study is aggregate data on the commercial status of biomass pyrolysis ventures (includes MSW, tires and plastics[1]). The definition of a ”venture” in this study is admittedly generous: a company website promoting such technology or just a mention in the media without a website. The entries go back to the 1980’s in a few cases, but most ventures were formed since 2000. Data were collected for this report until February 2016.

Evaluation of the commercial status of these ventures is carried out by screening publically available information, especially company websites and trade-industry publications. The stages of commercial development of new ventures have been defined in this study as:

- Proof of Concept: early stage and bench-scale/garage operations
- Prototype: pilot plants (includes small-scale and mobile units in commercial use)
- Demonstration: industrial-scale equipment in continuous operation
- Beyond Demo: more than one industrial scale plant in continuous operation but growth is slow as commercial viability of the technology is still uncertain
- Commercial: economics of process have been proven on an industrial scale and are competitive.

Proof of Concept is a catchall category for very early-stage ventures that includes:

- research groups
- “sheep-clothing” equipment suppliers who have placed a new sticker on a traditional piece of equipment - such as biomass rotary dryers which are then reborn as torrefaction reactors - yet have never been tested as such
- project developers or technology representatives/licensees who have never operated a pilot facility.

The next category, the Prototype stage, also includes commercially-used, small-scale and mobile units (viable businesses can be developed from small-scale and/or mobile equipment, but, for this study, the focus is on larger-scale equipment). Separating Proof of Concept and Prototype ventures is not always easy from the vague statements in start-up websites (overall, if there is doubt as to the commercial status of a venture, it is placed in the less advanced category).

A more relevant stat as to the health of the sector is the Demonstration stage of commercial development, but many claims of demonstration scale are still unproven, as the facility has never operated on a continuous basis for weeks or, preferably, for several months.

The category Beyond Demo is introduced to describe the few ventures that have truly gone further than one demonstration plant, but not much more. However, despite their success, members of this category cannot, as yet, be described as fully competitive and cannot be classified as Commercial by my definition. No pyrolysis-type technologies were found to be fitting the Commercial classification.

[1] By definition, tires and plastics are not biomass, but they are part of MSW (municipal solid waste).

The 1000

The distribution of the over 1000 pyrolysis ventures is roughly divided equally between the E.U., U.S. and the rest of the world.

Aggregate Data of Pyrolysis Ventures - Technology and Region

	European Union	United States	Canada	Rest of World	Total
Torrefaction	56	52	21	13	142
Steam Thermal	1	2	1	0	4
Pyrolysis-slow	94	89	29	108	320
Pyrolysis-fast	36	28	17	12	93
Hydrothermal Liquefaction (HTL)	3	6	1	4	14
Hydrothermal Carbonization (HTC)	6	0	2	0	8
Biomass Gasification	167	144	49	69	429
Total	363	321	120	206	1010

The pyrolysis ventures are further categorized by whether they are still active. Table values below in blue reflect active ventures still believed to be in operation (or, at least, their websites appear to be). Statistics in red reflect the inactive and defunct ventures, including:

- Websites "under construction," dysfunctional, or dead
- Stale (no updates since 2012) websites
- Ventures in financial distress
- Ventures not operating.

Aggregate Data of Pyrolysis Ventures - Technology and Stage of Development[2]

	Torref.	Steam Thermal	Pyrolysis Slow	Pyrolysis Fast	HTL	HTC	Gasif. Biomass	Total
Proof of Concept	42/37	0/1	90/42	21/16	4/0	2/1	109/62	268/159
Prototype	32/9	0/1	113/36	26/6	8/2	4/1	135/37	318/92
Demonstration	10/12	2/0	20/8	7/16	0/0	0/0	33/22	72/58
Beyond Demo	0/0	0	5/6	1/0	0/0	0/0	18/13	24/19
Total	84/58	2/2	228/92	55/38	12/2	6/2	295/134	682/328

[2] Numbers in blue are active, and numbers in red are inactive; data from this table are illustrated in the graphs below.

TORREFACTION – 142 entries

Torrefaction had witnessed exceptional growth from 2005 to 2010 but has since waned. The number of torrefaction ventures are inflated by standard equipment suppliers of kilns and furnaces, who have the potential to produce torrefied biomass, but little, if any, testing has actually been done (such companies have been categorized as Proof of Concept). The actual torrefaction process is relatively straightforward; the more challenging technical aspect is the production of a high-quality pellet, which few have been able to do.

STEAM THERMAL (STEAM EXPLOSION) – 4 entries

There are only a few steam thermal ventures, but the latest ones have made significant progress. It will be interesting to see if this sector gains traction.

PYROLYSIS - SLOW – 320 entries

Slow pyrolysis is a more traditional technology for charcoal manufacturing that has seen renewed interest for the production of biochar. The data include a few industrial-scale charcoal manufacturing sites, which account for the number in Beyond Demo. There has been a surge in slow pyrolysis in the last few years for the treatment of tires and the production of recycled carbon black (100 ventures are listed).

PYROLYSIS – FAST – 93 entries

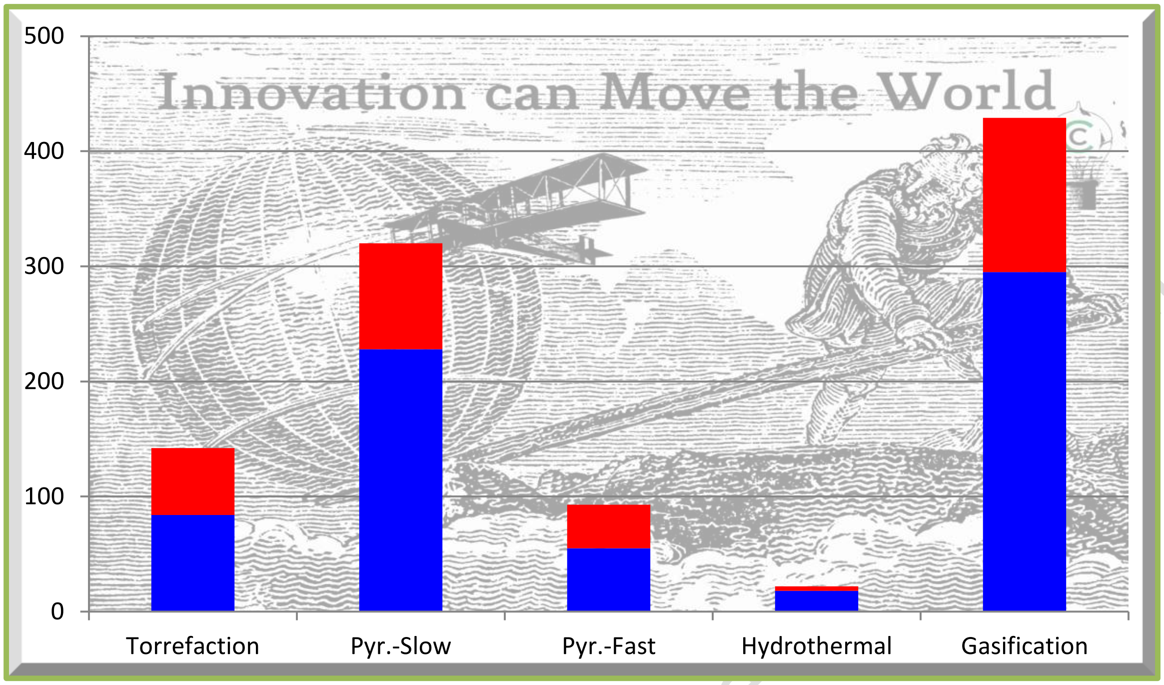
Fast pyrolysis is more technically challenging than the others. Holding back its development is the major product, pyrolysis oil, which has yet to be shown to have a viable market. After thirty years of innovation, the product challenges have forced this sector back to the proof-of-concept stage of commercial development as research work focuses on up-grading pyrolysis oil through catalytic processes. Recently, some demonstration facilities have opened with a new generation of catalytic pyrolysis. There is one firm in particular who has progressed to the Beyond Demo stage of commercial development and is far ahead of its competition in this regard.

HYDROTHERMAL LIQUEFACTION/CARBONIZATION – 22 entries

The hydrothermal processes have never been as popular as the traditional slow and fast pyrolysis technologies, but recently there has been a rise in interest. A few firms are on the path towards demonstration. A special feature of this technology is that it reduces a common weakness of biofuels: a high oxygen content.

GASIFICATION – BIOMASS – 429 entries

Among the pyrolysis-type ventures, gasification is the most mature. Included in this group is MSW (Municipal Solid Waste) gasification (135 ventures are listed), where several full-scale facilities have been built (Beyond Demo). Many of these have operated in Japan, which has a very high cost associated with MSW.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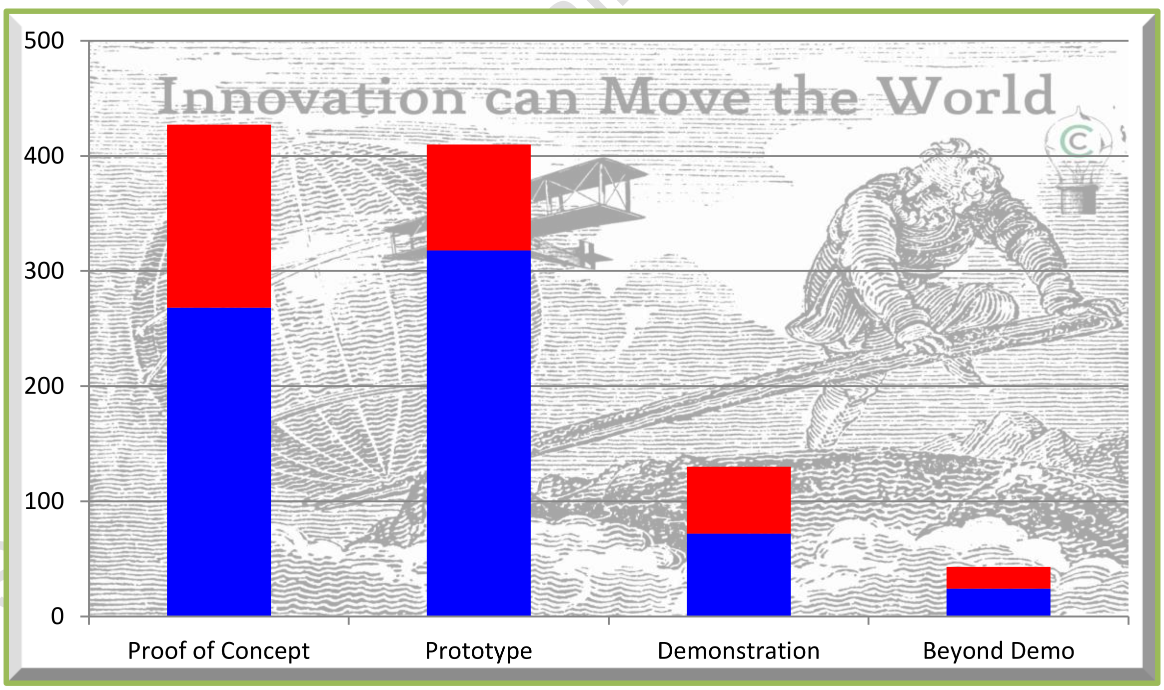
Innovation can Move the World
Torrefaction
Pyr.-Slow
Pyr.-Fast
Hydrothermal
Gasification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Innovation can Move the World
Proof of Concept
Prototype
Demonstration
Beyond Demo

DISCUSSION

The basic pyrolysis technologies had been invented decades, or even centuries, ago. The threat of climate change has inspired daring engineers, scientists, and mechanics to retrofit these processes from yesteryear. Over the past few decades, with renewed incentives to replace fossil fuels, a new generation of inventors and entrepreneurs have applied modern engineering and science to create a highly innovative, even brilliant, new generation of pyrolysis technologies.

Sixth Element has identified over 1000 such pyrolysis ventures. The numbers are misleading for among the "googol" of press releases (often picked up by popular trade publications and on-line media), most are from "virtual" wannabe companies and dreamy promoters whose success is determined by how long their websites remain "live," which is typically three to five years. The pyrolysis sector is an excellent case study of the new-venture millennials. The world of the commercialization of innovation has changed over the past few decades. Through most of the 20^{th} century (and before), entrepreneurs and inventors generally worked out of the limelight until a newsworthy development had taken place. With the venture millennials, as quickly as an idea or concept emerges, a new URL pops up and a LinkedIn profile, and Tweets quickly flood the internet. The downside of this virtual reality is that true technology leaders can be lost within the fog of social media.

The data presented in this analysis reflect the real challenges of developing a commercially-viable technology and make a mockery of the familiar announcements from start-ups that several facilities will be built in the coming years. Big SWAGs (scientific wild-ass guesses) are appropriate for dreaming about future potentials among the partners, but they have no place in formal business plans. In bad business plans, the most absurd SWAGs show up in the worst possible place: the *pro forma*. Entrepreneurs are often overcome by technology euphoria that masks economic reality; a prime example of which is the timeline to positive cash flow. A common financial model shows positive cash flow in year two. The problem is that you likely have no idea when "Year One" will begin and, when it does, to accomplish positive cash flow in only twelve months with a new technology is unlikely. The financial prospects will, no doubt, be exciting, but every failed project has had a hockey-stick profit forecast. The essential aspect of the *pro forma* is not the return per se, but the supporting evidence for the inputs/assumptions (where do the inputs and outputs come from?). Your profit-and-loss model is only as good as the certainty associated with the assumptions that have gone into it.

An especially irritating common SWAG in bad business plans is the futile claims of "best technology" (which is simply impossible to prove and only illustrates questionable judgement on behalf of the technology developer). Entrepreneurs should be extremely proud of their technology and venture, but they should never claim "best technology" in the business plan. Reporting the defendable advantages and strengths of the technology, process or product are what should be presented. Management may indeed believe in the SWAGs, but the real reason hyperboles are included in bad business plans is that entrepreneurs feel they must push the envelope to attract interest and investors. However, the opposite is true. Investors are attracted by trust in those behind the business plan, not indefensible hype, fanciful announcements, or naïve projections.

There are two basic questions in commercializing innovation:

Does the technology work?

Is there a customer for the technology or product at a price that gives a reasonable return?

Of course the technology works, or else you would not be attempting to commercialize it. However, there are different degrees of "working," which are used in the categories of the stage of commercial development in this study:

1) Proof of Concept
2) Prototype (may involve two or three scale-ups)
3) Demonstration (may involve two or three scale-ups).

On the road to commercial success, scale-up is king. A dangerous situation takes place when the venture chariot is put ahead of the technical horse; in other words, to cheat on scale-up by by-passing one or two of the stages, or to begin construction of a larger scale version of the technology before the testing of the present scale has been thoroughly examined and flaws have been rectified. The technology developer can feel forced to do so: more investment is necessary to resolve the remaining issues, but such funds can be impossible to raise for a facility that was never meant to have a positive return in the first place. To raise more funding, the venture jumps to a larger facility. The problem is the new facility costs much more to build, operate and repair; in other words, the cash drain has been greatly inflated, providing less time to fix any problems. By insisting on going on to the next stage before the present one has been properly commissioned, impatient investors, themselves, have placed their own capital at far greater risk. Pyrolysis ventures need patient investment.

A related topic is that "traditional" waste heat, power generation, by-products, or other value-added options can be assumed to be bolted-on to the new technology, without being properly tested. This is again a flawed assumption. If value-added options are part of the *pro forma*, they must be part of the various stages of scale-up.

A critical stage of technology development is continuous operation, which reveals new glitches in the technology or design of a process and provides more reliable operating cost data. Better to do this early than later, even though continuous operation will be a step-up in cash costs; it is always more expensive to discover such problems later on. Having operated the technology continuously for 7500 minutes is not a good guide to someone who wants to operate it 7500 hours per year. No customer wants to be a guinea pig to see how long a technology can operate before it has to be shut down.

While all technology developers have a virtual customer in mind, there are a surprising number that do not have solid marketing plans or have not even discussed their product/technology with potential customers. Altruistic claims by project developers are not enough to attract buyers of the product. And the marketplace is leery of new products/technology, even if it can save them money, as it introduces risk into their own operations: *caveat emptor*.

Why do so many new technology ventures fail even though so much sweat (and financial) equity has been invested by often brilliant, creative entrepreneurs? The answer is often poor business decisions in investments in time and money, and the choice of the wrong first project. There is never enough time and money; so the entrepreneur must manage them wisely. There are three ways of doing this:

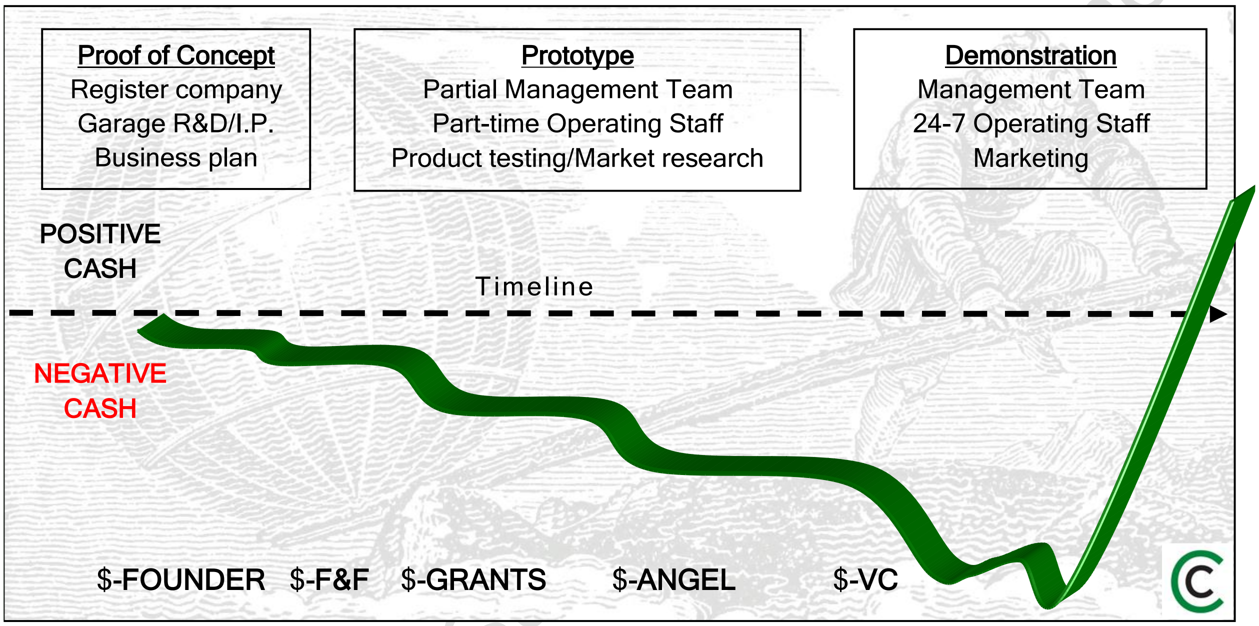
1) Focus
2) Focus
3) Focus.

While entrepreneurs always think that they have good reasons to look at multiple applications of their "platform" technology, such actions dilute progress, increase cash losses, and delay commercialization. While the technology can potentially take several routes, the entrepreneur must focus on the path to the quickest and safest positive cash flow that best fits the available resources (financial, technical, timeline, skill set, etc.). Other promising opportunities can be pursued later.

CONCLUSION

Commercial success among the over one thousand ventures in the pyrolysis sector has been elusive. However, these are the success rates that face the commercialization of innovation, especially of capital-intensive projects such as pyrolysis technologies, so be prepared to deal with it. The role of the technology developer in such high-stake ventures is to understand the risks and plan according: focus resources and time on the fastest path to get out of the Technology Valley of Death, namely into positive cash flow territory, as quickly as possible <u>but</u> without by-passing a key scale-up stage.

<u>Plot of Cash Flow by Stage of Development</u>



The commentary is not intended to be critical of any of the pioneers/entrepreneurs who are working to bring to market exciting and brilliant new products and technologies under such incredible odds. Especially, the Demonstration and Beyond-Demo ventures represent the best of the best and are leading the path for others to follow. The intent of the study is to ensure that the early-stage ventures prepare themselves for the challenging task ahead of them. Financing is the focus of most new ventures, but this is not enough, as shown by the failure of some well-financed ventures in the pyrolysis sector. Ventures often fail because of bad business plans rather than the technology itself. While investment is needed for the technology, it must be accompanied by investment in business planning.

If you wish to discuss aspects of this report, contact me at: gkutney@6esm.com.

Ashes denote that fire was;
Respect the grayish pile
For the departed creature's sake
That hovered there awhile.

Fire exists the first in light,
And then consolidates,-
Only the chemist can disclose
Into what carbonates.

Emily Dickinson (1830-1886)

SIXTH ELEMENT SUSTAINABLE MANAGEMENT

Sixth Element Sustainable Management is a "boutique" consulting firm specializing in **commercializing innovation**, and evaluating the business preparedness and commercial potential of technology developers and their projects. We provide executive management services for inventors, entrepreneurs, investors, and public sector agencies in new technology, start-ups and early-stage ventures. Services are directly provided by the Managing Director of Sixth Element Sustainable Management, Gerald Kutney, Ph.D. in chemistry.

Venture success depends more on management than the technology itself. Dr. Kutney has participated in all aspects of innovation and technology commercialization, from the research laboratory to patents to marketing to the executive suite. With two decades of executive experience in technology commercialization with global corporations and entrepreneurial enterprises, he brings the innovation of research and technology development, the financial discipline of big business, and the spirit of entrepreneurship to start-ups and early-stage companies.