Historical Innovations, Innovators and Generic Entrepreneurship Configurations

Using a historical perspective generic features for (chemical) innovation/entrepreneurship can be elaborated.

Read the following text. Note whatever you think or flashes across your mind is typical for (technology) entrepreneurship –

- Persons
- Participants/roles of persons,
- Situation, factors
- Activities, actions or processes,
- Concepts, etc.

Look only quickly across pages 1-9 and the Appendix which is for illustrative or explanatory purposes only.

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1. Chemical Business and Innovation/Entrepreneurship after Alchemy: 1704

The striking example, with an alchemy touch, is “Berlin Blue”, also called “Prussian Blue”, the “inorganic evergreen”. The name referring to Berlin points to the location where the “innovation” occurred, whereas the other name points to one of its major applications, bluing the coats of Prussian soldiers.

In 1704 Berlin blue was synthesized as the first (inorganic) pigment for coloration. It is non-toxic and not light-sensitive or photo-sensitive. It was *the first synthesized coordination compound*.

Due to wars in Europe at the beginning of the 18th century, natural pigments had become hard to obtain and were expensive. That led color makers to begin experimenting with ways to make pigments. One of these color makers was the German Heinrich Diesbach, who created Prussian Blue *by chance* in Berlin in 1704 while mixing up a “strange brew” that included ingredients such as dried ox blood. Other key ingredients were potash (a mix of KOH, K2CO3, and other potassium salts) and green vitriol (FeSO4).

The innovation success was based upon *communication and information sharing* with another person, J. C. Dippel, who did a business as an ingredient “supplier” and had a *commercial sense* and *appropriate market information*. The “Berlin Blue” story can be interpreted in terms of current thinking about entrepreneurship/innovation by "*generic entrepreneurship elements*" on the basis of Table 1.

In the workshop we shall elaborate basic terms and concepts of entrepreneurship and innovation.

Table 1: Timeline and typical entrepreneurship/innovation structures and the configuration for Berlin Blue – product and function orientations

Year	Situation and/or Actions	Comments and/or Structural Descriptions in Current Terms
1704		**1.** Due to wars in Europe at the turn of the 18th century, *natural pigments have become scarce and were expensive*
		2. In Berlin the chemist and "color maker" ("Farbenmacher") H. Diesbach was short of potash for the *intended preparation of a red dyestuff* and therefore asked the "chemist" J. C. Dippel for help. Potash actually was used in the form of "Dippel's animal oil" ("Dippels Tieröl", "Oleum Animale") and obtained by a "standard process" of heating animal bones and other animal-based waste products. Dippel provided his animal oil he no longer needed. When adding animal oil to the basic mixture, however, instead of a red color Diesbach got a blue color!
		3. Diesbach told Dippel about the observation. Dippel immediately recognized the big commercial potential of the finding: the coloration of the battledress of the Prussian army.

<table>
<tr><td></td><td></td><td>**4.** Furthermore, they took advantage from the *reduction of uncertainty* associated with their “innovation” by a *large source of guaranteed demand*, here *military procurement*.
(Probably based on good relationships and *trust and “common language”)* the innovator/discoverer and the supplier agreed to *cooperate* to jointly *enter the market* with a *low price* and give the product a name that is easily associated with the relevant product features and uses. “Berlin Blue”; related to the first use for the battledress of the Prussian army, it was also named “Prussian Blue”</td></tr>
<tr><td>1704</td><td></td><td>**5.** Dippel *improved the formulation* and kept it as a secret</td></tr>
<tr><td></td><td></td><td>**6.** Diesbach and Dippel went to Paris and produced there successfully Berlin Blue via their secret process under the name of “*Paris Blue*”</td></tr>
<tr><td>1710</td><td colspan="2">This quintessential inorganic pigment, later chemically identified as ferric ferrocyanide, Fe4[Fe(CN)6]3, was first synthesized by a German “color maker” and artist in 1704 as he attempted to make a red pigment. Prussian blue quickly became a highly desired substance and remained in strong demand until the 1770s. In 1710 it was described as being “equal to or excelling ultramarine”. Being about a tenth of the price of ultramarine, it is no wonder that by 1750 it was being widely used across Europe.</td></tr>
<tr><td>1724</td><td></td><td>**7.** The formulation of Berlin Blue *gets known in England*, where also production of Berlin Blue starts</td></tr>
<tr><td>1800+</td><td colspan="2">The *function* “bluing” *through a naturally occurring substance* could be replaced *by using a synthetic material.*
Competitive displacement of naturally occurring by synthetic chemicals and *vice versa* continues to govern chemical innovation for the next centuries (cf. also the “blueprint”).</td></tr>
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Ca. 1850	By the mid of the eighteenth century; in the market for bluing Berlin Blue and Indigo from India coexisted (in particular, in the Prussian army and the emerging textile industry)

Production of the blue color through the natural product “woad” got an entry into the German language as an idiom, which is an expression that usually cannot be translated literally into another language.

Its meaning is often quite different from the word-for-word meaning. The German word for blue is “blau.” However, if a German is “blau”, he is drunk, not sad. “Blau machen” (literally “making the blue”) means not to show up for work – for “good reason”. The story behind is as follows. It was found that the blue color becomes more intense, if during woad fermentation with urine alcohol (ethanol) is added. As alcohol was expensive, the “color guys” (“Färbergesellen”) drank this alcohol and later they added it indirectly to the fermentation broth via their alcoholic urine. Hence, if drunk “color makers” did not show up for work, they had “made blue color”. Simply, they were “blau”.Woad is in German the plant “Waid.”

2. The Birth of the Synthetic Dyes Industry in 1856: William Henry Perkin (1838 – 1907)

Table 2: Typical entrepreneurship/innovation structures and the configuration for the coal tar dye mauveine – product and function orientations.

Situation and/or Actions	**Comments and/or Structural Descriptions in Current Terms**
	There was a scientific vision of the famous German chemist Justus von Liebig in line with societal attitudes and convictions. We “believe that tomorrow or the day after tomorrow someone will discover a process ... to make the wonderful dye of *madder* (in German “Krapp” → alizarin) or helpful *quinine* or morphine from coal tar.” [Runge 2006:293]
	Following Liebig’s vision August Wilhelm Hofmann at the Royal College of Chemistry based in London targeted the demand of the market to have an antimalarial drug (quinine). Ball [2006] describes the chemical rationales at that time for selecting a specific route to synthesizing quinine. William Henry Perkin, a student of A. W. Hofmann of 18 years, had been directed to make the antimalarial drug quinine based on material from coal tar by an oxidation route. Initial trials with an envisioned starting material failed, but when using the coal tar product aniline things changed dramatically. “The resulting black sludge dissolved in methylated spirits, and the resulting solution was a beautiful purple.”
	Perkin “stumbled” over an unexpected result. Silk dipped in this solution took on the same royal hue. Perkin grasped that his purple solution could be used to color fabric. And Perkin took the recklessly bold move of quitting his studies to exploit the opportunity.

	Perkin realized that this coloring matter had the properties of a dye and resisted the action of light very well thus making it the world's first synthetic dye. He quickly grasped that his purple solution could be used *broadly* to color fabric. Perkin *changed the project direction* – he wanted to exploit the *first* synthetic organic dyestuff based on *abundantly available feedstock*. He sent some specimens of dyed silk to a dyeing firm in Perth, Scotland, which expressed great interest provided that the cost of the cloth would not be raised unduly. "It was to his credit, and luck, that he sought out the advice of Robert Pullar, the owner of a well-regarded dye works in Scotland. Pullar encouraged the eighteen year old Perkin to manufacture more dye, and told him that if the dyed fabric would remain color-fast and not fade in the sun, Perkin would be a very wealthy man." [Nelson 2002]
	Referring to this situation, Perkin filed for a patent in August 1856, while he was still only 18.
	Against Hofmann's recommendation Perkin believed in his business idea and convinced his father to invest in his idea and borrowed his father's life savings. With the help of his father and brother (*3F financing*), Perkin set up a **dye factory** in 1857 (Perkin & Sons) at Greenford Green, near Harrow, for mass production of the first synthetic organic dye – mauveine – on a six-acre site near the Grand Union Canal, not far from London. The *location* was selected for cheap transportation of coal-tar from London, the by-product for the emerging gas lighting infrastructure.
	Inventing the dye was one thing, raising enough capital for manufacturing the dye in quantity cheaply, adapting it to cotton, getting acceptance from commercial dyers, and creating demand for it in the public was something else. Perkin was active in all of these areas. In a whirlwind of activity, he got his father to put up the capital, his brothers to partner in the creation of a factory, (as a response to Robert Pullar's remark) he *invented a mordant* (a pre-dyeing treatment) for cotton, became a one man technical service operation, and publicized it in the marketplace.

	Utilizing the cheap and plentiful coal tar that was an almost unlimited by-product of London's gas street lighting the dye works began producing the world's first synthetically dyed material in 1857. Initially there were more *difficulties*. Since aniline was not readily available, it had to be produced at the factory from benzene. Manufacturing of synthetic dyestuff also revealed large *needs for inorganic basic chemicals*, such as sulfuric acid and alkalis, caustic soda, lime and soda ash.
	Already historic in its very founding, the company received an unexpected commercial boost from the Empress Eugenie of France when she decided the new color flattered her. In short order, mauve was the necessary shade for all the fashionable ladies of France. The product *met immediately a market with high purchasing power* based on fashion and "life style," and only *later expanded into the large end-user markets* via the co-evolving textile industry.
	Ten years after Perkin's discovery of (synthetic) mauve organic chemistry was perceived as being exciting, profitable, and of great practical use. Many other dyes and new firms followed, and Perkin & Sons was soon facing stiff competition from manufacturers in England and France. By the mid-1860s, the German (later giant) companies Bayer, Hoechst and BASF were already in business making dyes, as were Ciba and Geigy in Switzerland [Runge 2006:266-269] (and Figure II.20 in Runge [2006:275]). *Britain and France dominated the dyestuff industry till ca. 1870* to then encounter a dramatic decline through the new players from Germany. The important lesson learned is that the companies and industry of the country the innovation originated in do not necessarily win. A similar situation occurred currently: First the US leadership in the photovoltaic (solar cells) industry was overtaken by Germany, and currently both the US and Germany are behind China – and China having overcome both previous leaders. Perkin discovered and marketed also other synthetic dyes.

	Over the next few years, Perkin found his research and development efforts increasingly eclipsed by the German chemical industry, and in 1874, he sold his factory and retired from business, already a very wealthy man at the age of 35. He devoted the rest of his life to research in pure science. For instance, he became particularly interested in Faraday rotation and produced over 40 scientific papers on this topic. After Perkin's retirement from the industry he remained active in his field in other ways, such as being secretary of the Royal Chemical Society in 1869 and he became president in 1883. He also sat on the boards of several scientific journals.
	Results: *Industrial*: Perkin created and/or stimulated new industries (the organic color industry of coal tar dyes and pharmaceuticals); *Scientific*: He stimulated organic chemistry and the search for a better understanding of the structure of molecules

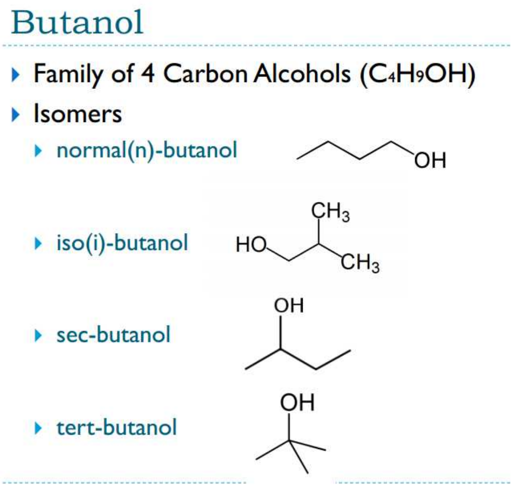
3. The Butanol Case as one of the Oldest Known Industrial Applications of Biotechnology
(Fermentation: Chaim Weizmann 1916)

Table 3: Selected raw material for biofuels [Runge 2014:Table I.97].

Situation and/or Actions	**Comments and/or Structural Descriptions in Current Terms**
	The production of butanol by biological means was first performed by Louis Pasteur in 1861. In 1905, Schardinger found that acetone could similarly be produced. Fernbach's work of 1911 involved the use of potato starch as a feedstock in the production of butanol. Acetone–butanol–ethanol (ABE) fermentation is a process that uses bacterial fermentation to produce acetone, n-butanol, and ethanol from starch. It was developed by the chemist Chaim Weizmann and was the primary process used to make acetone during World War I, for instance, to produce cordite, a family of smokeless propellants developed and produced to replace gunpowder as a military propellant. The anaerobic process is similar to *how yeast ferments sugars to produce ethanol* for wine, beer, or fuel. It produces these solvents in a ratio of 3-6-1 (3 parts acetone, 6 parts butanol and 1 part ethanol).

	The historic *acetone-butanol-ethanol* (ABE) fermentation by *Clostridium acetobutylicum* is one of the oldest known industrial fermentations. It was ranked second only to ethanol fermentation by yeast in its scale of production, and is one of the largest biotechnological processes ever known. Industrial exploitation of ABE fermentation started in 1916 with Chaim Weizmann's isolation of the most well-known strain *Clostridium acetobutylicum* from the Clostridia Class (US Patent 1,315,585 – "Production of Acetone and Alcohol by Bacteriological Processes" by Charles Weizmann, London; patented Sep. 9, 1919, using preferentially maize (corn) or natural substances rich in starch). Butanol is an important industrial solvent and is a better fuel for replacing gasoline than ethanol. In conventional ABE fermentations the butanol yield from glucose is low, typically at ~15% (w/w). Weizmann used a naturally occurring micro-organism! The production of butanol is also limited by severe product inhibition. Butanol at a concentration of 10 g/L can significantly inhibit cell growth and the fermentation. Consequently, butanol titers in conventional ABE fermentations are usually lower than 13 g/L Weizmann is considered to be the father of industrial fermentation and discovered/invented his process while being a lecturer at Manchester (UK). Weizmann transferred the rights to manufacture acetone to the Commercial Solvents Corporation in exchange for royalties. In order to make ABE fermentation profitable, many *in-situ* product separation and recovery systems have been developed. The Weizmann process was operated by Commercial Solvents Corporation from about 1920 to 1964 with plants in Terre Haute, IN, Peoria, IL, and Liverpool, England. The largest plant in Peoria, IL used molasses as feedstock.
	However, since the 1950's industrial ABE fermentation has declined continuously. ABE fermentation was mostly not profitable after World War II, compared to the production of these solvents from petroleum and almost all butanol is now produced via petrochemical routes. The low butanol yield and butanol concentration made butanol production from glucose by ABE fermentation uneconomical.
	But ABE fermentation was attracting renewed interest after 2000 with an eye on biobutanol as a renewable biofuel

	Current interest is not only n-butanol, but also other isomers like isobutanol from various renewable resources or waste.

	 Butanol
	- Family of 4 Carbon Alcohols (C_4H_9OH)
	- Isomers
	  - normal(n)-butanol
	  - iso(i)-butanol
	  - sec-butanol
	  - tert-butanol

Technology Trajectories	**PRODUCTION** **Past** – Bio-butanol - 1910 – 1950 - *ABE fermentation from molasses and starch* **Present** – *Petro-butanol* - After 1950 **Future** – Bio-butanol Biotechnological routes - *“New” ABE fermentation* - Other biotechnological processes (Genetic Engineering, Metabolic Engineering, Directed Evolution etc. concerning microorganisms – GMOs –bacteria, microbes, yeast, enzymes or other micro-organisms) Thermochemical routes - Gasification of biomass or waste (“synthesis gas – syngas; Fischer-Tropsch (FT)-process)

	Key intermediates for bio-routes are: **C6 and C5 sugars**
	Examples of recently emerged biofuels/bio-butanol startups and some remarks:
ButylFuel LLC (US, founded 1991) [Runge 2014: 1056-1058]	The Biobutanol Veteran: It further developed and patented the original ABE process that makes the fermentation process more economically viable and competitive (by a continuous two stage anaerobic fermentation process without significant amounts of acetone or ethanol). In 2005 the founder (David Ramey) ran a conventional unmodified "2 Buick Park Avenue" car with no modifications across the US with 24 miles per gallon of butanol. Production of n-butanol with modified *Clostridium*: This patented technology claims to be able to produce 1.3 to 1.9 times more butanol (per weight of raw material). Acquired by Green Biologics in 2012
Green Biologic Ltd. – GBL (UK, founded 2003) [Runge 2014:Table I.95]	GBL focuses on the production of only n-butanol (not isobutanol) on the basis of ABE fermentation; follows genetic manipulation of microbes which circumvent "butanol toxicity". Its technology strengths and/or differentiator is a unique collection of thermophilic (heat resistant) microorganisms; used for high temperature processes. GBL's microbial platform technology provides flexibility across a "range of different feedstock" due to its options to use different microbial species and strains for specific feedstock
Cobalt Technologies Inc. (US, founded 2006) [Runge 2014:Table I.96]	Cobalt follows the ABE-process to produce normal butanol (not isobutanol) with modified *Clostridium* microorganisms thus increasing the amount of butanol produced to decrease cost Cobalt does not do genetic engineering but accelerates the evolution of the bugs to produce more product at higher concentrations by conditioning them (cf. Directed Evolution) It focuses on reducing consumption of energy and the consumption of water and new methods separating the butanol and water Traditional butanol separation (distillation) accounts for 40-70% of total production energy.
Gevo Inc. (US, founded 2005) [Runge Table I.99, 1080]	The focus is fermentation of all sugars including mixed (C6, C5) sugars to isobutanol which can be converted to 1-butene for producing synthetic rubber; has developed a proprietary process" based on "Protein Engineering of Biocatalysts" (to convert agricultural waste products into different types of renewable, alcohol-based, liquid fuels),

Butamax Advanced Biofuels [Runge 2014: Table I.83]	JV of BP and DuPont, process yields isobutanol Use of genetically engineered yeast; uses of a modified strain of *E.Coli*

APPENDIX

Table 4: Selected raw material for biofuels [Runge 2014:Table I.97].

- Agricultural residues: like corn stover or cobs or cornstalks (stalks that remain after the corn has been harvested), straw (from cereals), bagasse (the fibrous residue remaining after sugarcane or sorghum stalks are crushed to extract their juice);
- Municipal waste: paper trash and pulp, other municipal garbage, municipal solid waste (MSW);
- Residues from forestry, wood processing or “recycled” wood (for instance, from houses), construction and demolition wood waste, timber harvesting residues, wood chips (for instance, KL Energy Corp. using Ponderosa pines), sawdust, Cobalt Technologies also tried beetle-killed lodgepole pine feedstock;
- Highly productive (“energy-rich”) existing or cultivated grasses and trees: switchgrass, eucalyptus and hybrid poplar;
- Carbon-based waste, like old tires.

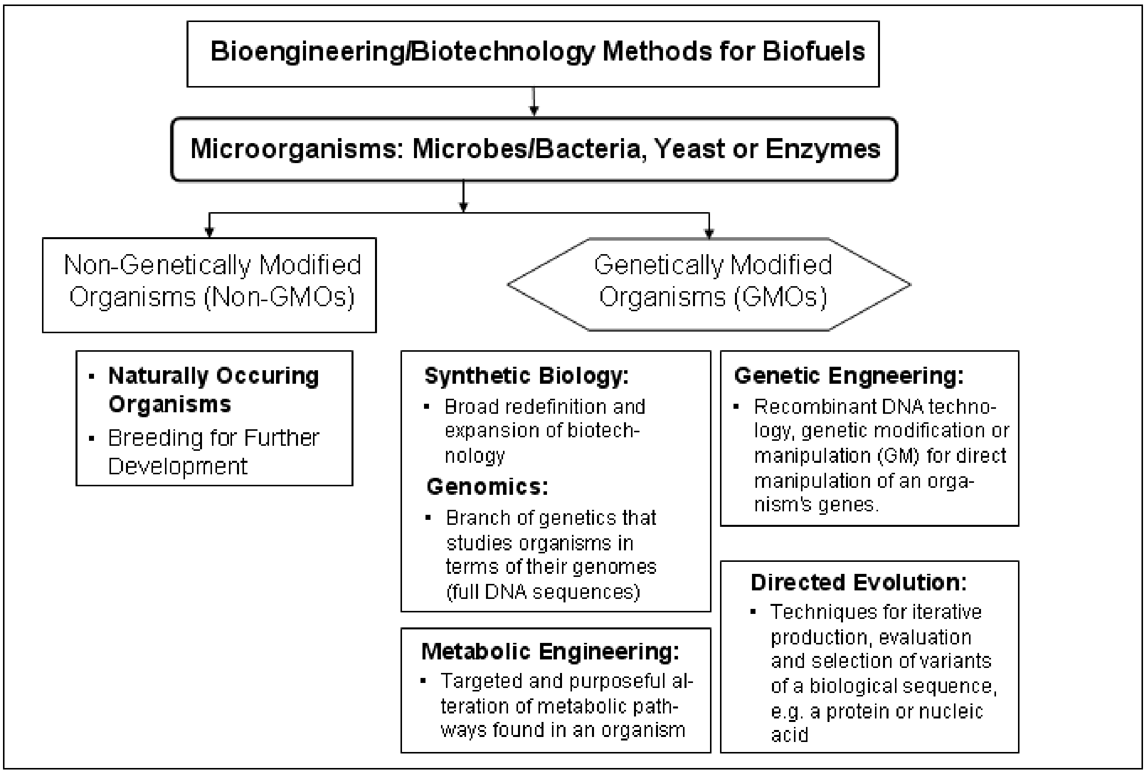


Figure 1: Bioengineering approaches to convert biomass including algae to biofuels [Runge 2014:Figure I.181].

As a conclusion the following chart shall be presented