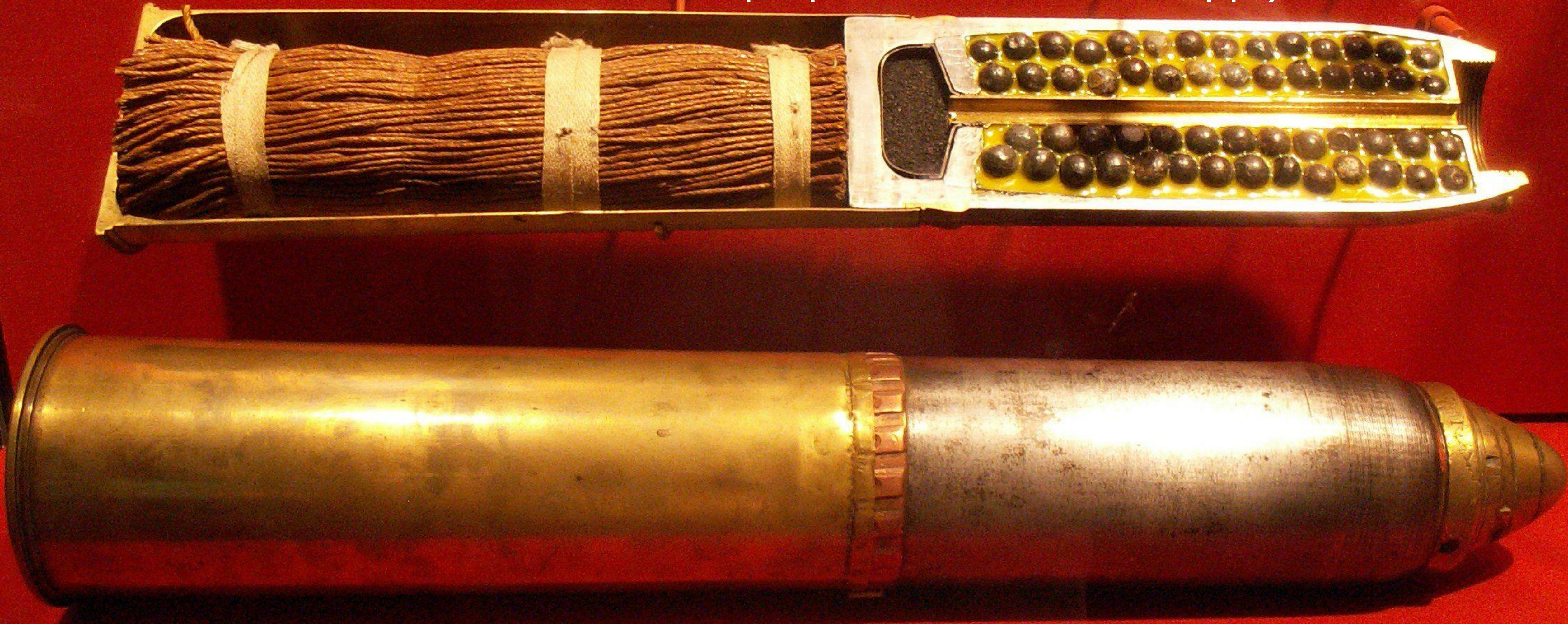
National Shell Filling Factory, Chilwell, UK

Over 2/3 of WWI battlefield deaths (out of 6 million) were caused by artillery. Disease killed another 3 million.

The British alone fired 170 million shells, or more than one per second, mostly along their section of the static Western Front, which was no more than 150 miles in length. This is an average of one shell every two minutes per mile of front – for 50 months.

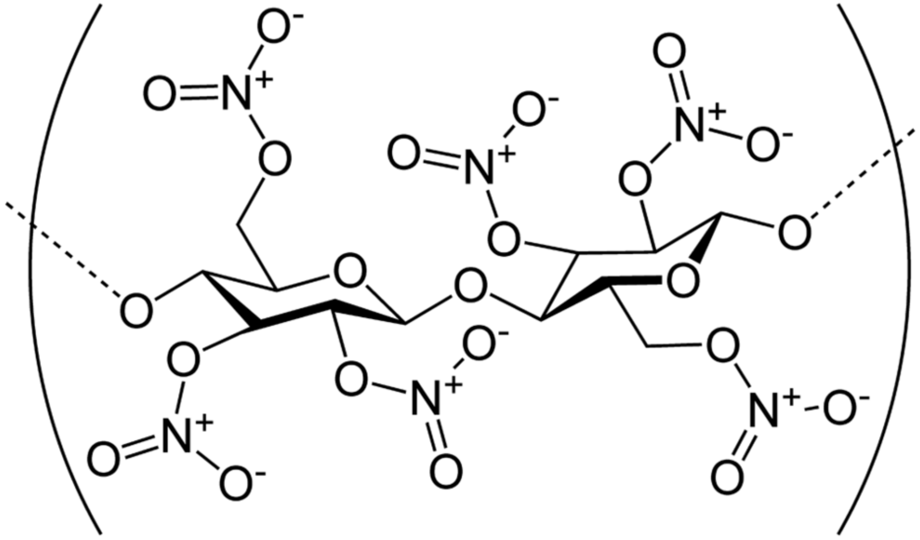
The intensity of shelling increased throughout the war. 1.7 million shells were fired during the first week of the Somme offensive of 1916, more than had been fired in the first year of the war (1914-15). 1.1 million shells were fired in the first American battle of the war, Saint-Mihiel, in September, 1918 – on the first day alone!

cordite – British propellant and a shell supply bottleneck



Propellant = gunpowder. By World War I, all combatants were using smokeless powders based on nitrocellulose and nitroglycerin, as opposed to black powders based on saltpeter (KNO_3).

cordite =



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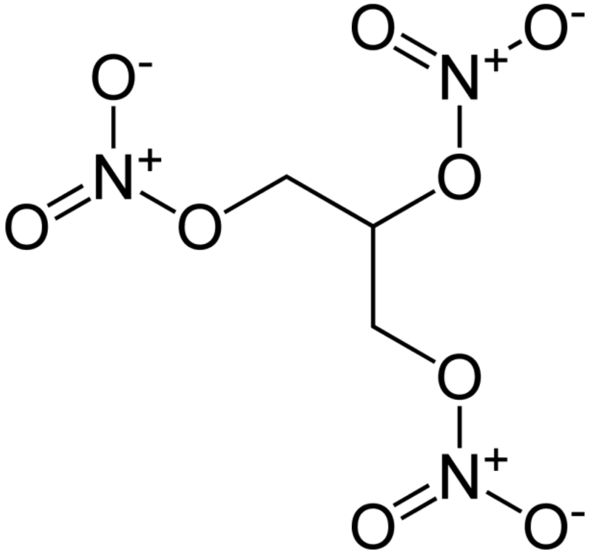
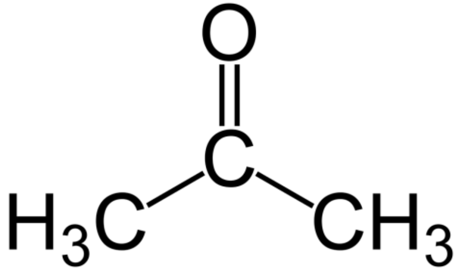


+ petroleum jelly

guncotton (nitrocellulose)
from cotton + nitric/sulfuric acid

nitroglycerin
glycerin from fats and oils
+ nitric/sulfuric acid

Acetone is used as the solvent to mix the components of cordite into a malleable, gelatinous form that could be extruded into “cords.”



Before the war, acetone was a byproduct of charcoal production by wood pyrolysis. The yield was quite low.

1,000 kg of dry deciduous hardwood yields:

50 kg of acetic acid

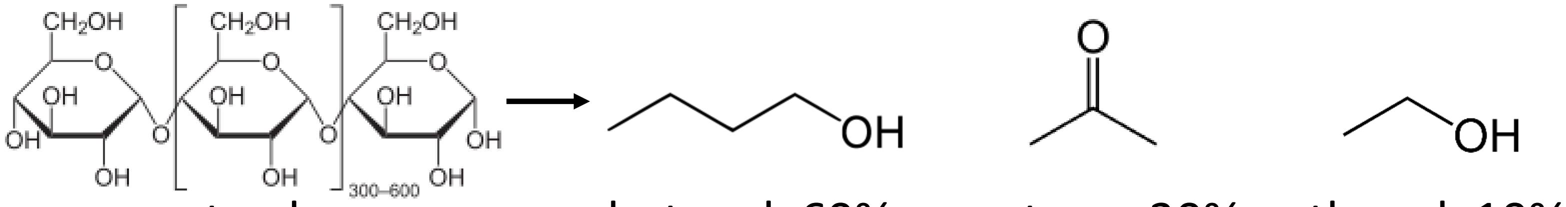
16 kg of methanol

8 kg of acetone and “methyl acetone,” or a mixture of acetone, methyl acetate, and methanol

Acetone production by fermentation: the origin of industrial fermentation

Acetone fermentation was discovered due to research on synthetic rubber production. Before the war, rubber came from trees rather than from cracking oil. Synthetic rubber could be produced expensively from other sources, as Germany was forced to do during the war, but was a shoddy substitute.

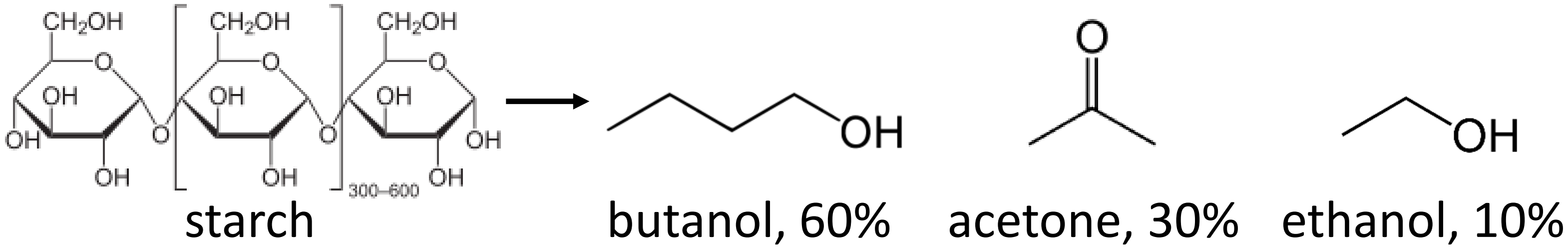
Another promising source of rubber was from newly-discovered microbes that fermented starch to butanol and acetone. (Later it was discovered that ethanol is also produced.) This bacterial metabolism is now known as acetone-butanol-ethanol, or ABE, fermentation.



starch　　butanol, 60%　　acetone, 30%　　ethanol, 10%

Acetone production by fermentation: the origin of industrial fermentation

The “Fernbach-Schoen” ABE isolate was used by a company in Manchester to ferment butanol and acetone from potatoes on an industrial scale. Although the process didn’t pan out for synthetic rubber – which, in any case, became abundant and cheap with booming Malayan production – the acetone attracted the interest of the British government with the outbreak of World War I. The isolate, however, grew slowly under strictly anaerobic conditions, and the factory only produced a few tons of acetone per month while thousands of tons were needed. A perceived shortage of shells contributed to the fall of the Asquith government in December, 1916.

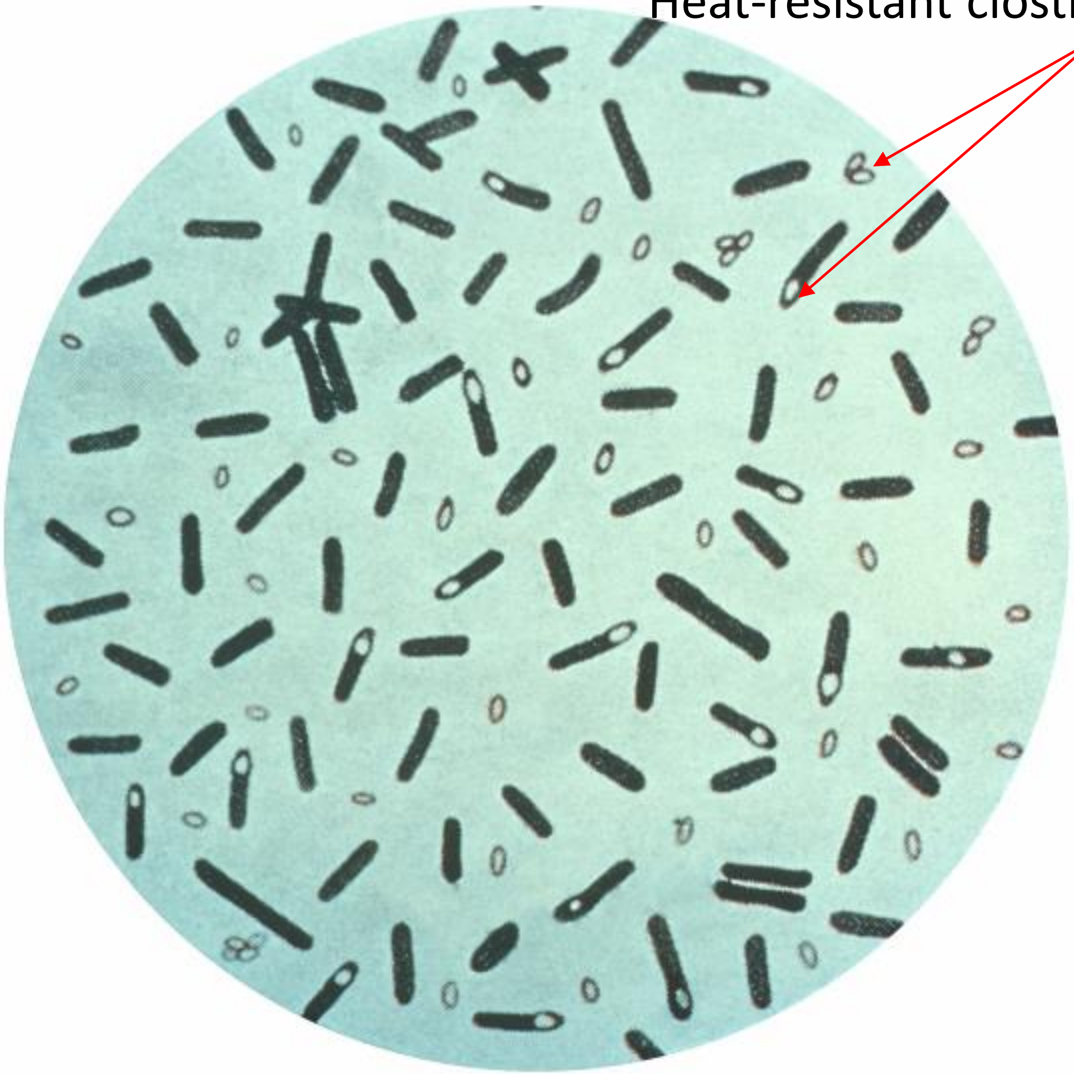


Chaim Weizmann

Clostridium acetobutylicum

"The Weizmann Organism"

Heat-resistant clostridial spores



Efficient aerobic fermentation of corn

UNITED STATES PATENT OFFICE.

CHARLES WEIZMANN, OF LONDON, ENGLAND.

PRODUCTION OF ACETONE AND ALCOHOL BY BACTERIOLOGICAL PROCESSES.

1,315,585. Specification of Letters Patent. Patented Sept. 9, 1919.

No Drawing. Application filed December 26, 1916. Serial No. 138,978.

Hitherto the production of acetone and alcohols by the fermentation of starchy bodies has been effected by means of bacteria *inter alia* by bacteria defined as of the type of Fitz. Fermentation of this kind has always been effected under strictly anaerobic conditions in closed vessels.

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The bacteria in question are found in soil and cereals, *e. g.*, maize, rice, flax, etc.

A convenient method of obtaining the bacteria above referred to is as follows:—

I prepare a number, (say 100), of cultures in the usual way by inoculating *e. g.*, hot (say 90° C. to 100° C.) dilute, (say 2%), sterile maize mash with some maize meal, and then allowing it to ferment at about 35° C. to 37° C. for about four to five days.

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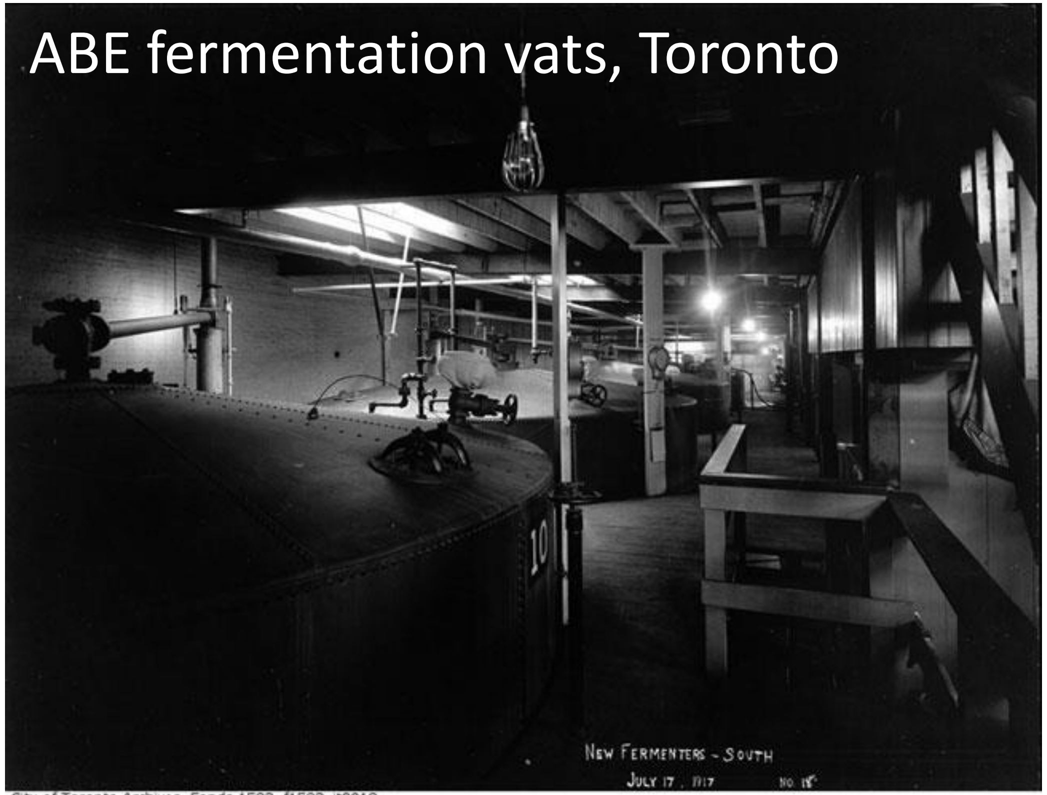
From these tubes I select those which show the most vigorous fermentation, and have a pronounced smell of butyl alcohol. These selected tubes I now heat up to from 90° C. to 100° C. for a period of one to two minutes. Many of the bacteria are destroyed, but the desired resistent spores remain. I next inoculate a sterilized maize mash with the culture which has been heated as aforesaid, and so obtain a subculture. I then heat this subculture up to 90° C. to 100° C. for one to two minutes, and use it to inoculate another sterilized maize mash, and repeat the foregoing subculturing operation a number of times, say 100 to 150 times. In these operations no special precautions need be taken for the exclusion of air.

"Well, Dr. Weizmann, we need 30,000 tonnes of acetone. Can you make it?"
Winston Churchill, First Lord of the Admiralty, upon meeting Weizmann in 1916

Within a year, ABE fermentation was scaled up. Fermentation greatly supplemented inefficient wood pyrolysis as a source of acetone; about 20,000 tons were produced by this method, principally in England and at plants in Toronto and Terre Haute. At the height of the U-boat campaign (1917), the government paid school children to collect acorns ("conkers") in an attempt to use these as a fermentation feedstock in lieu of imported American wheat and corn.



City of Toronto Archives, Fonds 1583, f1583_it0018

City of Toronto Archives, Fonds 1583, f1583_it0097

Ramifications

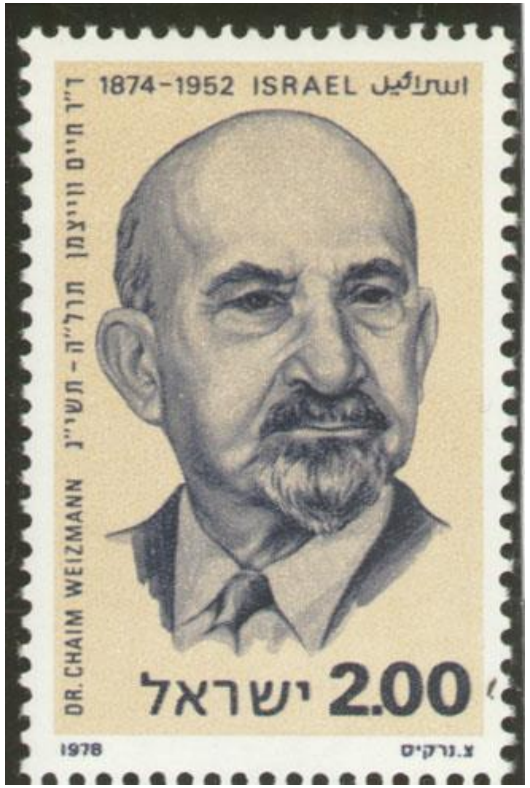
Ironically, the British acetone crisis was caused by the distinctive recipe of cordite, which differed from the propellants of all other combatants. Other propellants were variants of ballistite, which was gelatinized by collodion, or nitrocellulose in ether and alcohol, and was then flattened and chopped into flakes. In late 1916, the British began using a similar composition, replacing insoluble guncotton with soluble collodion, thereby alleviating the demand for acetone. However, British propellant maintained its characteristic stringiness and was still called cordite.


French *Poudre B*


An assortment of smokeless powders

Ramifications

As much as anyone, Weizmann, a dedicated Zionist, was responsible for the establishment of the state of Israel. British politicians were indebted to Weizmann for his contribution to the war effort; Weizmann himself suggests in his autobiography that the Balfour Declaration was a reward for his services. This is plausible considering his cordial relationship with Foreign Secretary Arthur Balfour and Prime Minister David Lloyd George from 1915, and his persuasive and persistent Zionist agitation. Weizmann founded a prestigious scientific institute in British Palestine and was appointed the first Israeli president, a largely ceremonial post (1949-52).



מכון ויצמן למדע
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Ramifications

The Balfour Declaration

Foreign Office,

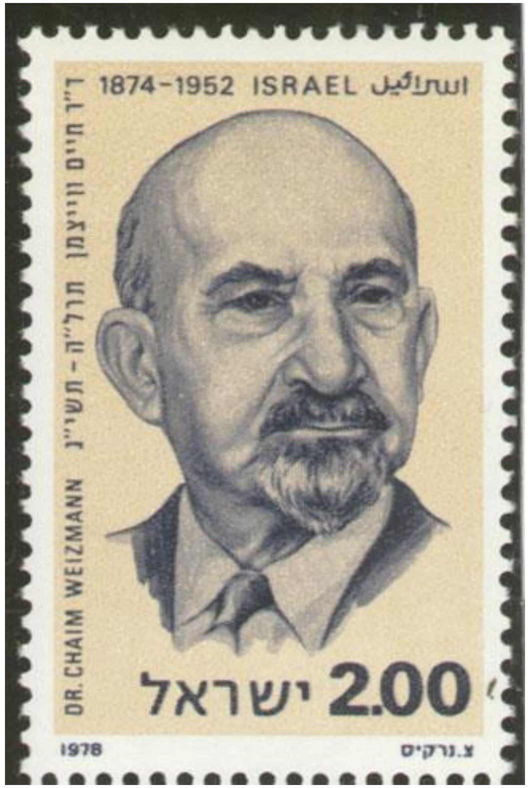
November 2nd, 1917.

Dear Lord Rothschild,

I have much pleasure in conveying to you, on behalf of His Majesty's Government, the following declaration of sympathy with Jewish Zionist aspirations which has been submitted to, and approved by, the Cabinet

"His Majesty's Government view with favour the establishment in Palestine of a national home for the Jewish people, and will use their best endeavours to facilitate the achievement of this object, it being clearly understood that nothing shall be done which may prejudice the civil and religious rights of existing non-Jewish communities in Palestine, or the rights and political status enjoyed by Jews in any other country"

I should be grateful if you would bring this declaration to the knowledge of the Zionist Federation.



מכון ויצמן למדע

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Ramifications

LETTER

doi:10.1038/nature11594

Integration of chemical catalysis with extractive fermentation to produce fuels

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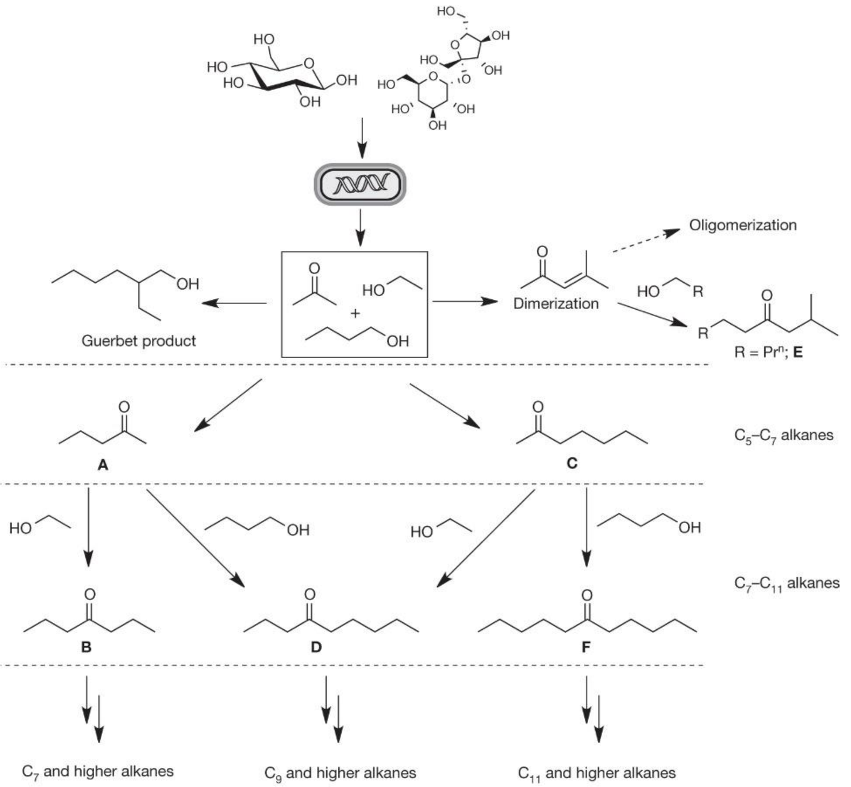

Nearly one hundred years ago, the fermentative production of acetone by *Clostridium acetobutylicum* provided a crucial alternative source of this solvent for manufacture of the explosive cordite. Today there is a resurgence of interest in solventogenic *Clostridium* species to produce n-butanol and ethanol for use as renewable alternative transportation fuels[1–3]. Acetone, a product of acetone–n-butanol–ethanol (ABE) fermentation, harbours a nucleophilic α-carbon, which is amenable to C–C bond formation with the electrophilic alcohols produced in ABE fermentation. This functionality can be used to form higher-molecular-mass hydrocarbons similar to those found in current jet and diesel fuels. Here we describe the integration of biological and chemocatalytic routes to convert ABE fermentation products efficiently into ketones by a palladium-catalysed alkylation. Tuning of the reaction conditions permits the production of either petrol or jet and diesel precursors. Glyceryl tributyrate was used for the *in situ* selective extraction of both acetone and alcohols to enable the simple integration of ABE fermentation and chemical catalysis, while reducing the energy demand of the overall process. This process provides a means to selectively produce petrol, jet and diesel blend stocks from lignocellulosic and cane sugars at yields near their theoretical maxima.

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