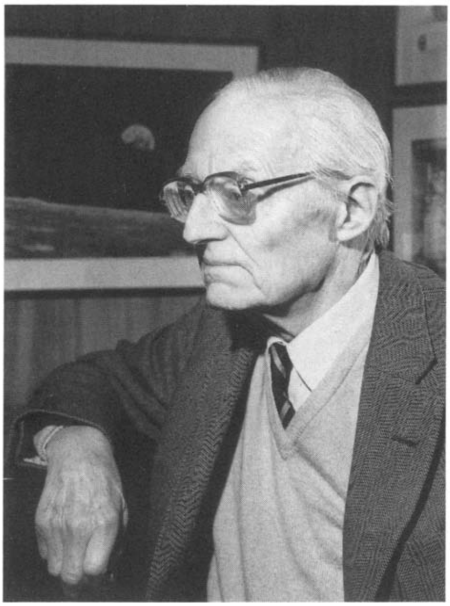
Grove Medal Presentation to F. T. Bacon, O.B.E., F.R.S., D.Sc., September 24, 1991



Ladies and Gentlemen:

It is a great honor and great privilege to address you in this historic auditorium, from the podium used for the famous lectures of Michael Faraday, the 200th anniversary of whose birth we celebrated last Sunday.

It is again a great pleasure to introduce Francis Bacon, Tom to everyone, the father of the modern fuel cell. As we all know, the fuel cell is an electrochemical battery operating at temperatures much lower than those normally used to turn the available energy of fuels into heat by combustion. This gives it thermodynamic advantages. It also means that it cannot produce oxides of nitrogen, so that its pollution is very low. It uses surface catalytic reactions, and therefore it requires clean fuel, which requires the extra cost of refining. This is not a disadvantage, since clean fuel has become an obligation today. It is also efficient, and can therefore make better use of precious energy resources. Better yet, it can be made clean and efficient in small units, which can give an effective doubling in efficiency, since they can use its waste heat for on-site co-generation. This should not only enable us to better use our fossil fuel reserves, but it also should allow us to reduce emissions of greenhouse gases causing global warming, particularly carbon dioxide.

When we gathered here two years ago, we celebrated the 150th anniversary of the invention of the embryo hydrogen–oxygen fuel cell by Sir William Grove. It was also the centenary of the invention of the fuel cell in a recognizably modern form, by Mond and Langer in 1889. Tom, after Eton and Trinity College, Cambridge, started

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thinking about fuel cells as a young man still in his twenties at Parsons in 1932. His work and friendship with Sir Charles Parsons, the inventor of the modern steam turbine, inspired him and made him think 'engineering' and 'practicality'. While at Parsons, he read Allmand and Ellingham's "Principles of Applied Electrochemistry", which included a chapter on fuel cell work up to 1924. He went on to read Grove's and Ludwig Mond's papers, and started thinking about fuel cell experiments in the 1930s. In 1940, at the beginning of the war, Professor Allmand invited him to King's College, London, to work on fuel cells. This was interrupted by more urgent work on antisubmarine warfare.

In 1946, he went to Cambridge to work with Professor Eric Rideal in the Department of Colloid Science. Professor Rideal had worked on fuel cells himself in 1914. Work continued in the Department of Metallurgy, then in the Chemical Engineering laboratory at Cambridge. The target was 100 mA/cm^2 at 0.8 V, using hydrogen, the fuel first used by Grove, and the most active practical energy source. In his early work, he used asbestos diaphragms with KOH electrolyte, somewhat on the lines of Mond and Langer. With his collaborator, Tom M. Fry, Tom asked Mond Nickel for porous nickel sintered plates for use as electrodes. They found that these could maintain a stable interface with a 2 psi gas pressure differential. They could then abandon the asbestos diaphragm, whose advantages they appreciated, but which leached out material which poisoned their electrodes and caused corrosion of nickel cathodes at 200 °C after as little as 20 hours.

A milestone was the discovery of lithiation of the nickel cathode, which prevented corrosion. The biporous electrode achieved higher performance and a more stable interface. The engineering approach familiar to Tom, who had no fear of steam turbines, suggested the use of high temperature and pressure to improve performance. A temperature of 200 °C at 41 atmospheres was used at first, which was later reduced to 27 atmospheres to avoid sealing problems. By the end of 1953, 230 mA/cm^2 at 0.8 V was achieved on hydrogen and oxygen at this pressure. By 1959, this was increased to 400 mA/cm^2. This was about the first time I had heard of a fuel cell, whose principle was explained to me as an undergraduate by Dr T. M. Sugden, later Master of Trinity Hall, in a supervision at Queens' College, Cambridge. As you can see, Tom has been associated with fuel cells more than twice as long as I have.

All Tom's work on fuel cells required patience and persistence. There were many disappointments when support was not available. For example, research was terminated and the team had to disband in 1955, even though a small 6-cell stack generating 150 W had been demonstrated by this time. In 1956, research was again supported by the newly formed National Research Development Corporation, and work was continued at Marshall's of Cambridge. By 1959, a 6 kW 40-cell stack operated, using circulating hydrogen for cooling. This required careful design of the circulation pump, which posed particular engineering challenges.

Ladies and gentlemen, the rest is history. In 1956, licenses were taken out by Leesona–Moos Corporation of the United States, and in 1959 by Pratt & Whitney Aircraft. They modified the cell to operate at 4 atmospheres to allow the use of lighter hardware, which was compensated by the use of a higher temperature to maintain performance. The Bacon cell then went to the moon, and in Neil Armstrong's own words, it made the Apollo program possible. Its successor, the Space Shuttle fuel cell, went back to using the original concept of using purified asbestos diaphragms.

In this last decade of this century, we may recall the work of two physical chemists in the last decade of the 19th century. At the first meeting of the Bunsengesellschaft, Wilhelm Ostwald looked forward in 1894 towards a new century in which an electrochemical engine, the fuel cell, would produce work, in preference to the smoky, polluting steam engine. He was wrong, because of the invention of the internal combustion engine. In 1886, using Langley's careful measurements of the absorption of heat from the moon's surface by the atmosphere as a function of lunar angle, Svante Arrhenius demonstrated that a doubling of atmospheric carbon dioxide concentration would increase global temperature by 5.6 °C, after accurately correcting for the effect of water vapor and nebulosity, i.e., the albedo of clouds. Unknown to Arrhenius, the measured result also included a doubling of the trace greenhouse gases, methane and nitrous oxide. Bearing this in mind, it is a very accurate prediction when compared with today's sophisticated atmospheric models. We see in these nineteenth century observations our present problems of pollution and the greenhouse effect, which may in part be solved by the fuel cell, the chemical power source of the 21st century for central electricity generation, dispersed power in homes, and transportation, and perhaps for other things as yet to be invented. As Tom himself says, this may include a new invention for the storage of hydrogen.

Tom is a direct descendant of Sir Nicholas Bacon, the Lord Keeper of the Great Seal Under Queen Elizabeth I. He is of the same family as Francis Bacon, Baron Verulam, the proposer of the scientific method, which Tom has used so well. His work has been the key to the development of modern fuel cell technology and he has been an inspiration to us all. To add to the other well-deserved honors he has received, including the Order of the British Empire, a Fellowship of the Royal Society, and a Doctorate of Science, we now add the Grove Medal. Appropriately, the medal is exactly five Troy ounces of platinum, which corresponds to the catalyst content in 25 kW of today's low-temperature fuel cells. It has a portrait of Sir William Grove on the obverse, and the gaseous voltaic battery of 1842 on the reverse. It is therefore with great pleasure that I present him, the father of today's and tomorrow's practical fuel cell, with the first Grove Medal.

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