Article

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FROM THE FPL TO PAPRICAN:

SCIENCE AND THE PULP AND PAPER INDUSTRY

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INTRODUCTION

Both Robert Borden and Wilfrid Laurier were present in the audience when H.R. MacMillan addressed a 1912 meeting of the Canadian Forestry Association on 'The Need for a Canadian Experimental Pulp and Paper Plant.'[1] MacMillan, then with the Dominion Forestry Branch, asserted that many sectors of the Canadian economy had received government subsidies, protection and other assistance. Agriculture, he argued, had benefited greatly from the Dominion Experimental Farm system; could not a similar form of government aid be given the forest products industries? He called for 'the establishing and maintenance of experimental laboratories where skilled chemists and pulp and paper experts will be encouraged to develop uses for woods, and wood waste now thought unsuitable for use in wood pulp manufacture.' Revenues from such improvements, he felt, would easily repay government expenditures and the country would benefit from the growth of the pulp and paper industry. The United States Forest Products Laboratory in Wisconsin cost $45,000 per year, a small sum when compared to the value of the industry's products. MacMillan went on to become one of the major figures in the British Columbia forest products industry. The vicissitudes of the research facility he recommended form the subject matter of this paper.

THE EARLY ENVIRONMENT

In the first third of the twentieth century, the pulp and paper industry underwent profound changes both in the role played by science and in its perception of the place of science. The two were closely intermeshed and were mutually reinforcing. Looking back thirty years from 1933, W.G. MacNaughton offered the opinion that 'at the beginning of the period under consideration, it is safe to say that the control of the processes depended entirely on the skill of the mill superintendent with the aid of his most skilled assistants.'[2] A form of the apprentice-journeyman-master route brought an individual to a leading technical job in a mill. Little or no attention was paid to waste materials. There was no differentiation in the basic processes among types of paper. The output volume was low. Over the next three decades, the Freeness Test and other developments gave the uniformity of

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stock needed for high-speed production. An intimate connection was established between control techniques and the apparatus of control. At the end of the First World War the industry still depended on Scandinavia for its skilled operators, who had received training in their native technical schools and apprenticed in their mills. Since 1914 great strides had been made in North American technical education, and increasing numbers of chemists and chemical engineers moved into positions of responsibility in Canadian mills.

The transition from the university to the mill was a difficult one. Especially in the early years, the information which the young chemist brought with him was often out-of-date or inapplicable, earning for him the general contempt of experienced operatives who may also not have shared his social background. This lack of practical experience not infrequently resulted in chemists finding themselves in positions of authority for which they were not qualified. In his testimony to the Cronyn Committee, McGill Professor R.F. Ruttan argued that Canadian mills were not able to compete in terms of quality with English, Swedish and Norwegian mills as the industry lacked the needed personnel with a university level training in pulp and paper science. When the artificial conditions of the just-concluded war ended, Ruttan warned, Canada would again be exposed to the full force of world competition. Only science could guarantee trading success so necessary to the Canadian economy.[3]

One of the first Canadian paper mill chemists was T. Linsey Crossley. His father had been manager at Grand'Mere for Laurentide and he himself was a chemist with Riordon Paper Company at Hawkesbury beginning in 1901. In later life, he recalled how the craft knowledge of all phases of the papermaking process had been jealously guarded and passed down from one generation to the next. 'Into the quiet valley of personal craftsmanship came a slow moving landslide of woodpulp, speed-up and demand.'[4] Crossley's first laboratory at Hawkesbury was an 8-x 10-foot space in which he did acid testing and design of equipment. For technical information he relied on *Chemistry of Paper Making* (1894) by Arthur D. Little and R.B. Griffin, and *Paper Maker's Handbook* (1902) by James Beveridge. When Crossley attempted to promote the idea of technical education, he was told by J.R. Booth, a leading paper capitalist, that 'the best school of paper making is the paper mill.'

The pulp and paper industry looked to the Dominion government for action on the creation of a research and training institution. When a correspondent for the *Pulp and Paper Magazine of Canada* (PPMC) approached a number of industry leaders on the subject he was told 'that is a question for the Government to provide for.'[5] Those within the industry who saw science as the key to progress organized a Technical Section within the Canadian Pulp and Paper Association (CPPA) during the First World War. Initiative for this action came from Linsey Crossley, C.B. Thorne of Riordon Paper, Roy Campbell, editor of PPMC, J.J. Harpell, President of the Industrial and Educational Publishing Company and John Bates, who was elected

chairman of the Section. The Technical Section formally came into existence at a meeting in the Château Laurier on 12 February 1915. Open to anyone interested in the technology of pulp and paper making, the new body had a wide membership of mill superintendents, managers, chemists and others. Its declared purpose was 'to stimulate interest in the science of pulp and paper making in Canada, to provide means for the interchange of ideas among its members, and to encourage original investigation.'[6] Members were elected by majority vote of the Section and dues were set at a dollar a year. *PPMC*, founded in 1903, became its official journal. The Technical Section and *PPMC*, in the following years, were to be ceaseless proselytizers for the cause of science in the industry.

THE FOREST PRODUCTS LABORATORIES

In the summer of 1913, estimates went through Parliament to establish the Canadian Forest Products Laboratories (FPL) at McGill. A year of discussions with Dr Frank D. Adams, the McGill Dean of Applied Science, had preceeded this. It was agreed that A.G. McIntyre, then editor of *PPMC* and Acting Secretary of the CPPA, be placed in charge of the work. The inaugural meeting of the CPPA passed a resolution in support of these plans. It had not been certain that McGill would be the site of the new facility. As it was a Dominion laboratory, Ottawa had an obvious claim, as did the University of Toronto with its Faculty of Forestry and Queen's University where Professor McRae had been conducting work on waste sulphite liquor. McGill, however, had excellent tests of materials equipment and its Department of Chemical Engineering had an involvement of some years standing with pulp and paper chemistry. As well, Montreal was the financial headquarters of the pulp and paper industry.

Though its work had been underway for some time, the FPL formally opened on Friday, 3 December 1915, at 700 University St. It had a staff of thirty of whom seven were on military service. Of the remainder, seventeen were technical personnel. The FPL, it was announced, would be involved with timber tests, timber physics, wood preservation, wood distillation and wood pulp. With regard to wood pulp, the proposed research programme included investigations into the use of trees other than spruce, the quality of paper made from sulphite, soda and groundwood fibres and the use of wood waste. The hope was expressed that there would be collaboration between FPL experimenters and those doing research in various mills.[7] An Advisory Committee was established consisting of Frank D. Adams, R.F. Ruttan, H.M. MacKay, Professor of Civil Engineering, F. Howard Wilson, President of J.C. Wilson Ltd., Carl Riordon, Managing Director of Riordon Pulp and Paper Co., Judson A. DeCew, President of Process Engineers Ltd. and R.O. Sweezey, General Manager, Montreal Engineering Co. Ltd. In one form or other the committee met two or three times a year until the autumn of 1919 when it became inactive.[8]

The FPL had difficulties in establishing a place for itself in the country's slowly growing research infrastructure.

Commenting on opinions it had received from industry leaders, the *Canadian Chemical Journal* remarked in 1919 that 'it would seem that there is a strong opinion in certain quarters that the Mines Branch in Ottawa and the Forest Products Laboratories in Montreal have not been run to the best advantage of the industries they represent.'[9] In part, this was due to the exodus of trained personnel from the FPL. O.F. Bryant, Chief of the Pulp and Paper Division, had resigned to become superintendent for Bennet Ltd. W.B. Campbell left as Assistant Superintendent of the laboratories to become Vice President of Process Engineers. H.N. Lee, Chief of the Division of Timber Physics left for a war-related job in the United States. E.K. Mansfield left for a position with a paper concern in Brooklyn. John Bates, who had replaced A.G. McIntyre as Superintendent in April 1914, himself left to join Price Brothers. R.W. Hovey, who had been another occupant of the post of Chief of the Pulp and Paper Division, left to take a research post with Abitibi Power and Paper. It should be noted that there was a deeper significance to this movement. When it was established, the FPL was almost the only employer for those who wanted a career in pulp and paper research. Through the war years, industry expanded its research activities to such an extent that it caused a supply shortage of competent personnel. If the government wanted to staff its laboratories, it would have to pay competitive salaries.

In the 1920s, the CPPA, McGill and the Department of the Interior attempted to arrive at a satisfactory arrangement with respect to the FPL. In the CPPA, it would appear that many at the managerial end of the industry who did not have a technical background became disenchanted with what they saw as the FPL's failure to produce obvious, tangible benefits. The CPPA offered to contribute toward the salary of a superintendent of the laboratories to make that position more attractive, but this was declined by the government. The Association then considered, but rejected, the option of taking over the Pulp and Paper Division of the FPL. Because of the First World War, expected new facilities to house the FPL were not constructed and it remained in its original building, which was inadequate to the point of being unsafe. W.W. Cory, the Deputy Minister of the Department of the Interior, originated a plan to move the FPL to Ottawa, ostensibly so that it could be provided with a more satisfactory physical plant. *PPMC* responded with a vitriolic editorial urging that this not happen but rather that existing facilities in Montreal be improved. Moving the FPL would mean that it would not be able to function 'as a semi-commercial intermediate stage between the fundamental scientific investigational activities of the University and the practical, mill-sized operations of a pulp and paper mill.'[10] Naturally, the editorial was particularly insistent that the Pulp and Paper Division be retained at McGill, as its value depended on close contact with the industry. McGill President Sir Arthur Currie commented that 'all the Pulp and Paper people are firmly of the opinion that these Laboratories should be left where they are and also that Ottawa is the last place on earth where they should be placed.'[11]

On the strength of resolutions passed at the annual meeting of the CPPA in early 1924 committing the Association to partial financing of pulp and paper laboratories, CPPA President George Carruthers led a delegation to Ottawa to discuss support for pulp and paper research. Nothing appears to have come of this and the pressure was kept up from the Department of the Interior for a move to Ottawa. In 1925, however, McGill and the CPPA came to an agreement to jointly remunerate a professorship in Chemical Engineering separate from the FPL. Half of the support for the new chair would come from the Association and the other half out of a bequest to McGill from the late E.B. Eddy. Dr Ruttan attempted to induce Bjorne Johnsen, a Norwegian cellulose chemist who had worked at the FPL for two years, to return to Montreal and accept the new post. Johnsen, then employed with Hammermill Paper Co. of Erie, Pennsylvania, declined the offer and recommended instead Harold Hibbert. While at Yale in 1920, Hibbert had written a 'Plea For the Scientific Study of Cellulose Chemistry.'[12] After reviewing all the products of cellulose -- textiles, pulp, fibres, cellulose nitrate and acetate, celluloid -- Hibbert regretted that little scientific study had been made of the economically important substance: 'All of these industries have been built up essentially on empirical data rather than based on deep-seated knowledge of the nature of the constitution of the cellulose molecule.' Hibbert urged industry to publish what results it had on cellulose, following the examples of General Electric with tungsten and DuPont with nitroglycerine. He felt that there was a need for a comprehensive English-language scientific textbook on cellulose as well as university chairs of cellulose chemistry and appropriate scholarships. In a letter to Ruttan, Johnsen praised Hibbert as very solid on cellulose chemistry. He did qualify his endorsement by stating that Hibbert was 'not sufficiently familiar with the processes of the Pulp and Paper Industry and could not be expected to teach students on this subject.'[13]

Whether because of this or because of Hibbert's notoriously difficult temperament, Ruttan advised Principal Currie, 'I do not think that Hibbert could fill the position which we have offered to Johnson [sic] as he is not the type that would appeal to the paper and pulp industry of Canada.'[14] This must have caused Sir Arthur a measure of confusion, as some days later one of the industry's leaders, C. Howard Smith, wrote to him, endorsing Hibbert as a candidate for the Eddy Chair.[15] Hibbert was named to the new professorship, and his appointment seems to have been well received.

At the 26 January 1926 meeting of the Research Section of the CPPA at which Hibbert's appointment was announced, a proposal was set out for a building at McGill to house Hibbert's laboratory, the FPL and the CPPA offices. On 15 April 1926 a report was submitted to the Executive of the CPPA noting the need for such a building and highlighting the inadequacy of the existing FPL accommodations. Under terms of an agreement reached later that year, the CPPA would pay for a new building and an endowment with $350,000 in bonds at 6%. The University would lease the building to the CPPA at a nominal rent for forty years after which it would revert to McGill.

Administrative and maintenance costs would be divided mostly between the CPPA and McGill with a small government share. The Canadian Pulp and Paper Research Corporation, the legal entity formed by the CPPA to carry out the functions relating to the leasing and construction of the building, along with the Building Committee and the Executive of the CPPA met 4 April 1927 and approved plans for the building.

What was congealing was the reality and the cognition of a system of technical advance in the industry. An editorial in *PPMC* saw a continuum from fundamental facts of the properties of materials, to the study of industrial processes to analytic methods for control of processes in mills.[16] At McGill, fundamental research would be done by Hibbert and his co-workers, the FPL would perform tests of processes and materials on a semi-commercial scale, while the CPPA would provide further applied research and input into the system from 'experienced manufacturers and managers.' It was noted that 'many McGill men are to be found in important positions in the pulp and paper industry ... the industry, therefore, has been largely the inspiration of problems for the laboratories to investigate and has been the absorber of the product of the University.' With the creation of the Pulp and Paper Research Institute of Canada (PAPRICAN) at McGill, this system would be institutionalized.

THE PULP AND PAPER RESEARCH INSTITUTE OF CANADA

PPMC, as might be expected, campaigned vigorously to obtain the widest possible industry support for the new facility. The bond issue was represented as a modest expenditure, 'less than the cost of a single modern paper making machine.'[17] Other wood-using industries were urged to support the retention of the complete Forest Products Laboratories in the new Institute. For the research system to work, the magazine reminded its readers (and such reminders were needed) that the cooperation of mill operatives was necessary to provide information and identify problems for the research institute and for continuous communication while the problems were being worked on. As well, such operatives must be qualified and willing to interpret and apply results. Thus in fact, *PPMC* and other boosters of pulp and paper science had no illusions that what they were advocating was a fundamental transformation of the industry. Noting the gulf between, as we would now say, invention and innovation, *PPMC* acknowledged that the process of technical change was intricate:

> The equipment manufacturer is not sure of the extent to which the new process or machine will be adopted, and this in turn rests, first on the ability of the mill executive to appreciate its earning power, and the operating department to be induced to change either mental attitude or mechanical apparatus, and on the necessity of extensive changes for the borrowing of more capital.[18]

PAPRICAN may be seen as one of the most conspicuous successes of the movement for scientific industrial research in Canada.[19]

It was not, by any means, an easy victory. While Canadian industry was becoming increasingly involved in research, the CPPA experienced some difficulty in selling its bonds. McGill had to increase its own commitment by subscribing for $75,000 worth of them itself. The cornerstone of the PAPRICAN building was laid 13 October 1927. Arthur D. Little wired his congratulations[20] and Col C.H.L. Jones of the CPPA declared that 'research is now an intimate part of all well constituted business.'[21] Jones stressed the partnership among business, the Dominion government and McGill and hoped that provincial governments would join in. Continuing the theme of an integrated research system, he stated that the Institute would 'weld together the Faculty designed for the purpose of pure research, and the business side of the industry.' What was not welded together was as significant as what was. Only the Pulp and Paper Division of the FPL was to be retained at McGill in PAPRICAN, the rest of the Laboratories being transferred to Ottawa. Thus, pulp and paper research was henceforth to be conducted within a context of cellulose chemistry, rather than one of general forest products concerns.

In a series of articles in *PPMC*, Leslie McFarlane introduced the new Institute.[22] Mechanical progress in the industry, he stated, had been dramatic, while the underlying chemical research and understanding which was the basis was less so. Over the preceding decade this had been recognized and more attention and resources had been devoted to it. The need to pool research had also been recognized. PAPRICAN brought together an experimental pulp and paper mill, Hibbert's department, the Pulp and Paper Division of the FPL under E.P. Cameron, testing laboratories and the offices of the CPPA. As well, McGill was home to Otto Maas's Department of Physical Chemistry. Industry had donated a considerable amount of machinery to PAPRICAN. The twenties had seen growing awareness of the relative importance of the chemical and biochemical study of the raw materials of the industry. Basic research, it was argued, was necessary for industrial progress even if much of the data of such research was not directly applicable. Hibbert's department had already done valuable work for the industry in such areas as temperature-pressure diagrams for aqueous solutions of SO_2 which were widely used in the industry and the chemical influence of cooking acid on cellulose and pulp bleaching. Soon, the department would take up the nature of beating, the role of alum, the utilization of waste sulphite liquor, the utilization of screenings of waste wood and the manufacture of a purified pulp comparable with cotton cellulose for rayon.

The programme of E.P. Cameron's Pulp and Paper Division[23] was to 'define and develop methods of analysis and testing, designed primarily for the use of the laboratories, but with the ultimate idea of standardization by the pulp and paper industry in Canada and possibly foreign countries.' It would process and evaluate information from the industry and act as a clearing house for ideas. The Technical Section of the CPPA expected that tests of freeness, sedimentation, unbeaten and beaten strength of pulp would lead to broad investigation of ground-wood pulp production, sulphite cooking and other major topics. The CPPA Research Section was studying

chemical methods of analysis with respect to cellulose, alpha cellulose, the copper number, lignin, baryta resistence, the properties of SO_2 solutions and the conditions governing the formation of a sheet of paper on the Fourdrinier machine. The testing labs were of especial interest to the industry and could carry out all standard tests. PAPRICAN installed a laboratory to calibrate the Canadian Standard Freeness Testers. These laboratories would test pulp and preparation of uniform, standard sheets for testing unbeaten pulp in a wet-testing room. By mid-1929, more than one hundred Freeness Testers had been calibrated and sent out to pulp and paper mills and laboratories.

The creation of PAPRICAN resulted in a number of administrative alterations with respect to the CPPA. Six years previously, responsibility for research had been taken from the Technical Section and given to a special committee, later the Research Section. With the establishment of PAPRICAN this responsibility was returned to the Technical Section. The bulk of the CPPA's $140,000 annual budget was in fact going to support research, $20,000 of it in an annual grant to PAPRICAN. To administer and control the co-operative research work of PAPRICAN, a committee was set up with representatives from the CPPA, the Dominion government and McGill. The CPPA named its representatives F.A. Sabbaton of Canada Power and Paper, former FPL head John Bates and J.J. Buncke of Abitibi Power and Paper. In addition, CPPA Secretary Edward Beck sat on this Administrative Committee.

The FPL had had the misfortune of coming into existence at the outbreak of World War I, while it was PAPRICAN's bad luck to open its doors on the brink of the Great Depression. Thus its early years were grim ones for the Institute, just as they were for the industry. By 1931-32 virtually all Canadian mills were in bankruptcy or near it. Reorganization took place as price and output negotiations floundered. The low point with regard to production came in the first quarter of 1933 and with regard to employment in the second quarter of 1933. Under such circumstances, pulp and paper industry leaders were little inclined to support research science. At the 1930 Annual Convention of the Technical Section, CPPA, 'it was pointed out that the technical laboratories were not in a position to render real service to the industry.'[24] That is, PAPRICAN had no miracle solution to the industry's woes.

The Institute was not without friends. When Harold Crabtree, then President of the CPPA, addressed the Annual Convention of the Technical Section in 1932, he argued that there was a need for new lines of production to solve unemployment problems. Thus he felt more attention should be paid to commercial research, that is, closer cooperation among salesmen, mill superintendents and technical men. Substituting paper products for other types of products he thought could be a viable industry strategy. Research, he insisted, should not be given up in a time of depression.[25] Sir Arthur Currie added a not-disinterested plea for the maintenance of research efforts by industry, declaring that 'research is not a luxury, it is a necessity.'[26]

Other elements of the technical system were faring as badly. A 1933 report of the CPPA Committee on Education documented the drastic curtailment of technical education activities due to the Depression. The Three Rivers (Québec) School of Papermaking, in the previous year, saw its registration drop from fourteen to only two. The associated Technical School experienced a drop in registration from 305 to 225. Most graduates were unable to find employment. The same situation existed at other schools expected to produce the new type of worker the industry felt it needed. The Institute of Industrial Arts in Gardenvale, Québec awarded only ten diplomas, down from fifteen, while new registration dropped from twenty to seven. In New Brunswick, the Edmunston Pulp and Paper School, according to the report, would not be offering classes in the fall.[27]

In the 1930s it was the Dominion government, with its $40,000 annual grant to the McGill operation, which kept PAPRICAN going. From 1932 to 1936 the CPPA was able to grant only an average of $3,750 per year. The Association's own revenues had been cut in half by the Depression. In 1934, with newsprint prices at about $40 per ton, it appeared that the CPPA might pull out altogether. But PAPRICAN's supporters in the industry organized a voluntary levy to raise money. It has also been alleged that the CPPA directly subsidized Hibbert's salary by $4,000 per year during the Depression.[28]

Of course PAPRICAN did survive and prosper, eventually moving into extensive new facilities in suburban Pointe Claire. In the words of one scholar, it is 'a model of inter-sector integration'[29] in a country where government-industry-university cooperation has often been weak. In addition to the Freeness Test, the FPL-PAPRICAN has made significant contributions to the understanding of the fundamental chemistry of sulphite pulping, the hydrating of pulp by beating, alkaline cooking of wood for pulp, pulp bleaching, grinding, the development and standardization of laboratory methods and testing procedures.

CONCLUSION

The succession of the FPL by PAPRICAN at McGill was mirrored by, and intimately related to, changes in the nature of the Canadian pulp and paper industry. In 1913 it was, to use the contemporary term, a wood-using industry. Its technical basis consisted of the pulping processes developed during the nineteenth century and implemented by experienced craftsmen. The industry maintained an arms-length relationship with the new government research facility it shared with other forest products industries. Twenty years later the industry was, and perceived itself as, a cellulose industry. It could boast perhaps a dozen in-house research and development units and scores of professional chemists. Its trade association, the CPPA, was housed with an integrated research facility oriented to the chemical problems of the pulp and paper processes.

NOTES

N.B. This is an abbreviated version of a paper presented to the seminar in Canadian history at York University, May 1982. The issues will be discussed at greater length in the author's PhD dissertation.

1. *Pulp and Paper Magazine of Canada* [hereinafter cited as *PPMC*] 10 (April 1912), 115-19.

2. 'Process Control during Thirty Years,' ibid. 34 (Convention Issue 1933), 71-3.

3. Ruttan's testimony is found in the committee's *Proceedings* for 13 May 1919.

4. 'Before We Became Technical,' *PPMC* (May 1953), 163-6.

5. 'Technical Education in the Paper Mill,' ibid. 11 (1 Jan. 1913), 6-7.

6. Ibid. 13 (1 March 1915), 123 *et seq.*

7. Ibid. 12 (1 August 1914), 447-8.

8. Memorandum prepared for Arthur Currie re FPL by Professor Ruttan, 22 October 1921. McGill University Archives [hereinafter cited as MUA], Acc. 641, Box 291.

9. 'First-Hand Opinions of Government Assisted Research,' *Canadian Chemical Journal* 3 (January 1919), 15-16.

10. 'Are the Forest Products Laboratories for Service or Entertainment?' *PPMC* 21 (18 January 1923), 15-16.

11. Currie to Herbert Marler, 19 October 1922. MUA, Acc. 641, Box 291. This controversy should be seen in the context of the struggle for National Research Council laboratories in Ottawa then ongoing.

12. *Chemical and Metallurgical Engineering* 22 (1920), 838-9.

13. Johnsen to Ruttan, 30 June 1925. MUA, Acc. 641, Box 291.

14. Ruttan to Currie, 9 July 1925. Ibid.

15. Smith to Currie, 24 July 1925. Ibid.

16. 'A Mecca for Cellulose Researchers,' *PPMC* 23 (29 Oct. 1925), 1239-40.

17. 'Put it Over,' ibid. 24 (1 July 1926), 755.

18. 'The Gap Between Research and Production,' ibid. 25 (17 March 1927), 345-6.

19. For the concept of a movement for scientific and industrial research in early twentieth century Canada, see the article by Philip C. Enros in this number and his 'Towards a History of Research and Development in Canada: Industrial Research in Ontario, 1900-1930,' unpublished paper presented at the Annual Meeting of the Canadian Society for the History and Philosophy of Science, Ottawa, 11 June 1982.

20. Little to Currie, 13 October 1927. MUA, Acc. 641, Box 291.

21. 'Dedication of the Pulp and Paper Research Institute,' *PPMC* 25 (27 October 1927), 1353ff.

22. Ibid. 27 (2 May 1929), 641-6; (9 May 1929), 677-80; (23 May 1929), 755-8; (6 June 1929), 831-4.

23. Ibid.

24. Ibid. 31 (25 June 1931), 755-8.

25. Ibid. 32 (11 February 1932), 143-4.

26. Ibid., 145-7.

27. Ibid. 34 (Convention Issue 1933), 97-9.

28. Charlton to Currie, 18 March 1932. MUA, Acc. 641, Box 291.

29. G. Bindon, 'Output Measures of Cooperative Research: the Case of the Pulp and Paper Research Institute of Canada,' *Scientometrics* 3:2 (1981), 85-106.