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ABSTRACT

The technology of storing apples in refrigerated controlled atmospheres (CA) began spreading from New York to other states during the early 1950s and was introduced in all the major production areas by 1957. Economic and scientific factors were responsible for regional differences in diffusion of CA technology. The economic factors included high early-season prices in several short-crop years and low intraseasonal price differentials as U.S. apple production increased during the 1950s. A scientific dispute over the benefits of CA for certain western apple varieties also contributed to the uncertainty of adoption. Robert Smock and his students (Van Doren, Southwick, Dewey, Mattus) at New York's Cornell University pioneered the research, development, and adoption of CA technology during the 1940s and 1950s. Others, chiefly USDA researchers, advocated improved traditional handling practices over adoption of CA technology.

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The technology of storing apples in refrigerated controlled atmospheres (CA) began spreading from New York to other states during the early 1950's and was introduced in all the major production areas by 1957. (1) By the early 1960's, about 40 percent of the northeast's apple storage capacity was CA-enhanced, about 30 percent in the midwest, 7 percent in the south, and 10 percent in the west. The adoption of CA in eastern states came early, partly because New York's Cornell University had Robert M. Smock and his students to pioneer the way from experimental to commercial application. The predominant eastern varieties--McIntosh and Jonathon--were also notoriously susceptible to low-temperature storage disorders, and CA technology doubled their storage life to compete directly with western varieties during spring and early summer months. But controlled atmosphere technology was expensive to install and required improvements in management before its benefits could be realized.

In Washington, a prolonged debate among scientists about the benefit of CA for the predominant western variety--Delicious--may have delayed adoption. But after 1957, the Washington apple industry increased CA capacity at a rapid rate. Washington's initial reluctance to adopt the technology changed with new economic developments in the apple industry and new scientific leadership in postharvest horticulture. The high cost of CA installation and management coupled with a certain skepticism among postharvest researchers during the 1940's and early 1950's may have been important factors in Washington's apparent lag in adoption.

Before making the investment required to adopt CA technology, a rational innovator would want some assurance that it was effective and would expect to recover the added costs from higher prices for CA apples. Adopting CA technology required substantial capital outlays, more managerial inputs, and a marketing strategy for late-season months when competition from other fruits was intensifying. Installing CA could mean renovating a regular cold storage; but with the requirement for a complete seal, new construction was the preferred alternative. Adopting CA technology was risky because it was unproven, and the economic environment was rapidly changing as production technology improved and consumers began demanding fewer, higher quality apples. To partially offset the added capital, management, and risk required to adopt CA, the cost of trial and error could be reduced by scientific expertise familiar with proper installation and operation. Still, it was necessary to show positive benefits from CA before adoption could be expected.

Dalrymple refers to the "long 'wind-up' period...As often happens, some professional--and possibly personal--differences of opinion existed" that would explain why postharvest pomologists debated the benefits of CA. (2, p. 48) Although Dalrymple details the technical develpment and some of the economic aspects of CA technology, I will

concentrate on the scientists involved in the research and development of CA in the United States and the economic environment facing U.S. apple growers. After examining the regional differences in scientific and economic problems in the U.S. apple industry of 1940 to 1960, I conclude that the scientific debate over CA was important in Washington's late entry, perhaps as important as economic factors.

Origins of CA Technology

The knowledge that modified storage atmospheres would slow the ripening of fresh fruits and thus lengthen their period of availability originated from Montpellier, France in 1821 and Cleveland, Ohio in the 1860's (Dalrymple, op. cit.). But, not until the 1910s did the English "gas storage" research of Kidd and West at the Low Temperature Research Station at Cambridge lead to the first widely recognized potential for using modified atmospheres in cold storage. Several English varieties of apple benefited greatly from a combination of low oxygen, high carbon dioxide, and temperatures 10 to 15 degrees higher than normal cold air storages. By 1937, the English cold storage industry had 29 million cubic feet of CA capacity, over 80 percent of their total fruit storage space. More than 200 commercial CA facilities were installed in England. (3)

An important feature of this technology was the 90 days necessary for the treatment benefits to become evident. Shorter treatment periods resulted in fruit of no higher quality than regular cold air storage. This was not a limiting feature, though, because the economic benefits of extended storage were derived precisely from the need to hold apples off the market during fall and winter months when supplies were greatest. Extended storage meant that apple growers could increase output beyond the limits previously set by perishability and strengthen their bargaining power with processors who often were credited with causing low prices in years of oversupply.

The 1930s mark the beginning of scientific recognition of CA technology in the United States. In 1928, E. L. Overholser at the University of California at Davis reported on experiments with avocados in modified atmospheres but dropped the idea and, in 1930, went to Washington State College. Sustained U.S. research on CA storage of fruits began with the work of Frank Wisdom Allen at the University of California. Allen came to California in 1920 from Washington where he had worked on fruit ripening at Washington State College, the state's Agricultural Experiment Station, and the UDSA's Bureau of Markets. His research on carbon dioxide injury in stored Yellow Newtown apples led to an interest in the British research of Kidd and West and to the first U.S. commercial test of "gas storage" in California in the fall of 1933.

Robert M. Smock, after receiving his Ph.D. from the Ohio State University, joined Frank Allen at the University of California in 1935. (4) Smock and Allen experimented with apples, pears, plums, and peaches for about three years, using small scale chambers to measure a wide range of atmospheres, and reported their results in 1937 to the American Society for Horticultural Science (ASHS). (5) Their CA experiments with Yellow Newtown apples showed the possibilities of storage at 40 to

45 degrees Farhenheit for the same length of time as with regular air at lower temperatures but with none of the internal browning associated with this variety.

Smock moved back to his home state New York in 1937 to accept an offer from Cornell University in the Pomology Department, where he and his graduate student, Archie Van Doren, tried different room-sealing techniques, various atmospheric mixtures, and experiments with McIntosh apples--a variety notorious for deterioration after several months of storage at 32 degrees F. Van Doren had grown up in the fruit growing area of Wenatchee, Washington and attended Washington State College (B.S., 1937) before coming to Cornell. A year after Smock arrived at Cornell, he left for England to observe the research of Kidd and West, and returned with first-hand knowledge of the English storage industry. While Smock was in England, Van Doren continued his research with McIntosh, testing the CA effect on storage life, fruit physiology, and post-storage marketability. With Van Doren's help and his own "...philosophy that changes are brought about by the actions of dedicated people", Smock began the research and extension activities that led to recognition of his being a "pioneer in the area of 'controlled atmosphere' storage". (6)

Changes Come to the Apple Industry

During 1940 to 1960, the U.S. apple industry passed through a period of decline into growth following the introduction of new technology in production and marketing. (7) Because of several short-crop years, the Office of Price Administration maintained favorable wartime ceilings on the price of apples until 1945; but by the 1950's, new technologies became available to control and increase production and necessitated development of improved storage and marketing to prevent late-season losses. As apple trees required five to seven years from planting to harvesting the first commercial crop, growers with an incentive to increase production in 1945-47 were later to see the problems of selling the large supplies in a free market.

For the 1940-1949 period U.S. apple production declined at an average rate of one percent per year. In the 1940's, the combined New York and Michigan apple production averaged 21 million bushels--less than half its 1910-14 average--while the emerging industry in Washington more than quadrupled to 28 million bushels. Missouri, a leading apple state in the early twentieth century, dropped steadily until it was only a minor state by 1950. (8) From 1950 to 1959, because of higher yields, improved cropping control, and the new pesticides, U.S. apple production increased at an average rate of 1.8 percent a year. In the late 1940's, eastern and western apple harvests were about equal and accounted for 80 percent of total U.S. production. By the late 1950's, eastern producers increased their share to 47 percent while western producers dropped to 33 percent. Only part of the increase in eastern production was sold in the processing market for apple sauce, slices, and juice, where CA storage was not widely used and where western apples did not compete.

The varieties planted by apple producers after World War II also changed as consumers apparently demanded greater size, color, and uniformity of fruit. McIntosh became increasingly important in New York and Michigan as its share of production went from 25 percent in 1942-46 to 29 percent in 1952-56. Similarly, Delicious production in Washington went from 48 percent to 53 percent of its varietal total. So, while Washington was becoming more of a "one variety state" with no processing industry to serve as an alternative outlet, the U.S. fresh market was becoming increasingly competitive, especially with eastern apples being packed and shipped for truck and trailer transportation to rapidly growing urban markets, such as Chicago, St. Louis, and Los Angeles. (9)

Competition in Late-season Markets

Before CA technology arrived in New York, McIntosh was held in refrigerated storage no later than about January. But in the 1950's, CA technology allowed New York growers to hold McIntosh for late-season markets--the traditional outlets for Washington Delicious. Both potential and actual U.S. apple production were increasing, so to avoid low prices in the November-December market, growers were forced to invest in storage and compete for a share of the April-June market. The net result was that Washington lost market share to New York and Michigan. (10)

The breakeven cost of storing apples was about 28 cents a bushel for standard refrigeration in the early 1950's, and to cover the added costs for CA, the price differential between November and May had to be about 50 cents. In the ten seasons from 1946/47 to 1955/56, the average Washington November-May price differential was 50 cents or more only 3 times (actually negative twice) compared to 6 or more times in New York and Michigan (Table 1). But, although Washington's average late-season price differential was usually less than breakeven until 1958, the differential for certain premium Washington apples was consistently high enough to justify investment in earlier years. (11) Economic forces countering adoption may have been Washington's short crop in 1951 and national short crops in 1952 and 1953 which led to high early-season prices, and Washington's built-in alternative to CA in the hardy Delicious. Therefore Washington may have had less economic incentive to adopt CA than their eastern counterparts.

A significant difference between Washington's and New York's markets was related to differences in product. McIntosh was regarded as a premium dessert apple and it competed effectively with the upstart Delicious during early-season months. The price of McIntosh was usually higher than average, and CA-stored McIntosh were now appearing later in the marketing season. Besides the intrinsic differences among varieties, CA-stored apples had to meet precise requirements of proper maturity. Meeting these requirements meant that CA fruit would be the highest quality and presumably command above-average premiums, but buyers had difficulty telling the difference in CA fruit based on outer appearance alone.

Table 1. Monthly average price received for apples, 1946/47-1955/56

State	November	February	May
	Dollars per bushel		
New York	2.05	2.16	2.46
Michigan	2.12	2.31	2.61
Washington	3.03	3.17	3.45
United States	2.34	2.61	2.86

SOURCE: United States Department of Agriculture, Agricultural Prices, Crop Reporting Board, monthly issues. See Appendix Table 3

The need to differentiate CA apples from their regular storage competition led New York to pass state legislation in 1957, barring the use of the CA label in New York markets unless the fruit had actually been treated for at least 90 days with a prescribed atmospheric combination of gases. Michigan and California followed suit, using New York's basic format to set their state regulations. States with CA laws were marketing a product which exceeded, indeed was outside of, USDA standards for fresh-market apples. In the early 1950s, Washington had attempted to solidify its place in late-season markets with the revised USDA grades, specifing Extra Fancy for the first time as a national standard. But, by 1961, Washington introduced CA legislation in response to industry individuals who had or were planning to invest in CA and wanted to compete in New York City, Detroit, and Los Angeles. (12)

Smock and Former Students Aided Adoption

The adoption of CA in Washington and other states was economically feasible by the early 1950's, but the process required more than just installation of the equipment needed to control the storage atmosphere. Because of precise requirements that varied with the kinds of apple, seasonal factors, and marketing strategies, research into local conditions was necessary before commercial success could be expected. Only apples with the proper "internal" qualities would benefit from CA treatment and not all varieties benefited the same. Knowledge of the history of a particular crop was necessary to accurately predict when to harvest, and storage had to be accomplished on the same day. Stringent requirements about the length of time to achieve proper atmospheric conditions and fruit temperatures meant that storage operators had to rely on the expertise and close supervision of postharvest fruit specialists, at least initially.

Before recommendations could be made with confidence, scientific research over several seasons was required to gain the experience in local conditions and to demonstrate the technical benefits of CA. The

experimental variation among different lots of fruit harvested in one year was large enough that multiple year trials were required for adequate replication. Getting growers and storage owners to see the benefits of CA required a combination of familiarity with local problems and sound experience in the field of postharvest pomology. The pattern of adoption, not surprisingly, followed the location of Smock's former graduate students.

Smock's research program during the 1940's and 1950's resulted in several of his students being hired by major apple producing states to bring CA technology to their industries. Van Doren (Ph.D., 1941), the most notable example of this influence, returned to his home state Washington in 1947 and eventually became superintendent of the Washington State University Tree Fruit Research Laboratory in Wenatchee. In 1957, Van Doren convinced his friend, "Bones" Marley, to experiment with a regular storage room by converting to CA with a plastic film liner, thus the first CA came to Washinton 16 years after Van Doren graduated from Cornell. F. W. Southwick (Ph.D., 1943) went to the University of Massuchusetts in 1948, where he influenced CA adoption in the entire Northeast, beginning in 1951. G. E. Mattus (Ph.D., 1949) went to Virginia, where adoption in 1959, though lagging New England, was the farthest south CA technology extended. D. H. Dewey (Ph.D., 1950), upon going to Michigan, helped growers there begin CA storage in 1956, principally for McIntosh and Jonathon. Smock spoke to the Michigan Society for Horticultural Science in 1956, in which he praised the expert leadership of Dewey and I. J. Pflug (an agricultural engineer) for the research they were doing to adapt CA technology to Michigan conditions. (13)

Skeptical Scientists Disputed the Need for CA

In 1939, at the annual meeting of the ASHS in Columbus, Ohio, Van Doren presented his CA research with McIntosh apples. He reported a doubling of the storage life of McIntosh and hypothesized that CA treatments caused a "residual effect" that gave a longer post-storage market life. The residual effect was shown to be related to the level of carbon dioxide, but the mechanism was not known. Smock had reported the apparent residual effect in 1938, but no explanation was given. (14)

The following year, at the annual meeting of the ASHS in Philadelphia, researchers from the USDA's Wenatchee laboratory questioned the need for CA. They reported CA experiments with apricots and peaches that showed "While it usually required from 1 to 2 days longer for the gas-stored fruit to attain optimum dessert quality than for similar lots held in air, the length of time such fruit remained in prime dessert quality was not significantly different from that stored in air. In other words, there was no apparent 'residual effect' from the use of carbon dioxide gas that would lengthen the period over which the ripened would be consumed. If a temperature of 36 degrees F could be maintained in refrigerator cars, the use of carbon dioxide in the shipment of peaches would not be justified." (15, p. 248) This was one of the earliest statements by researchers at the USDA that doubted the commercial value of CA technology. Through the 1940's and 1950's, the

USDA held fast to the philosophy that commercial storage houses in the west, at least, could do more to improve the quality of fresh fruit by using traditional handling methods of picking at the correct stage of fruit maturity, careful packing, and proper temperature control in regular cold storage. They pointed out that the Delicious varieties in the west stored well under refrigeration and that CA technology was too expensive.

The battle lines were clearly drawn after 1940 between those who recommended CA technology and those who recommended that improvements in traditional postharvest practices were enough to prevent certain low-temperature storage disorders. Part of the reason may have been the difference in research priorities between the two groups. The USDA group focused on transportation and handling, while Smock's research program was focused on longterm storage disorders. The difference was a natural result of the differences in variety and distance to market. Washington growers sought the advantage of new refrigerated rail cars for shipping long distance to eastern markets while New York was interested in longer periods of storage to expand its markets. Even so, the question of CA in Washington was argued by the two camps for the entire period from 1940 to 1960. (16)

At the 1952 meeting of the Washington State Horticultural Association, Van Doren explained the details of CA storage with emphasis on Golden Delicious and Delicious apples. He presented no experimental results nor did he reference any particular studies of CA with northwest grown fruit. The first reference to the benefits of CA on Delicious varieties followed a lengthy discourse on how and why CA technology works. "Golden Delicious and Red Delicious apples respond best and can be kept longest with oxygen at 2 percent, the carbon dioxide less than .05 percent and the temperature 31 degrees F...Golden and Red Delicious stored promptly when properly matured have been kept in excellent condition not only through April, May and June of the following spring, but were in prime condition one year after being placed in the modified atmosphere storage." (17, p. 92) Van Doren went on to tout the residual effect of CA on post-storage marketability and explained the technical details of CA storage operation. In addition to the brief nature of these remarks about Delicious and Golden Delicious, Van Doren offered no data to support his position on the benefits of CA in Washington.

At the same meeting, the USDA researchers countered with conclusions that CA offered no benefit above what could be gained with traditional methods. Fisk Gerhardt and G. F. Sainsbury had only recently found soft scald to be a problem for Washington Red Delicious, and soft scald was the principal storage disorder prevented by CA in McIntosh. (18) They blamed the trend on a combination of delayed storage and subsequent rapid cooling by more efficient modern refrigeration. The delay in storage arose from a shortage of adequate labor to harvest and move the fruit into cold rooms the same day. The delay and subsequent rapid cooling of fruit to 31 degrees F were conditions thought to cause soft scald in apple, generally. Rather than recommend CA technology, Gerhard and Sainsbury focused attention on solving problems from "seasonal and cultural factors" (pg. 99). It was

recommended that fruit thus made susceptible to soft scald should be held at 34 degrees F for 8 weeks prior to 31 degrees F air to "...assure excellent protection against soft scald...Much of the Delicious tonnage, however, with optimum maturity and handling is being placed immediately at 31 F or lower in the newer types of cold storages without the subsequent development of soft scald." (p. 99) Gerhardt and Sainsbury cited as confirmation the 1945 research of Gerhardt and Smith "...wherein the influence of storage practices on the quality of Delicious apples received detailed investigation." (p. 98)

Seven years earlier, Gerhardt and Edwin Smith concluded "The need and practicability of using modified air for the storage of northwestern-grown Delicious apples has not been demonstrated. The results of the present study show that, with preferred methods of handling, it is possible to store Delicious apples in normal air at 31 degrees F until April and still market the fruit with acceptable dessert quality." (19, p. 169) The 1945 study was a major research effort by the USDA and a positive finding about the benefits of CA in the 1950's would have required explaining the previous doubts. But "The Delicious apple as grown in the Northwest is relatively free from most physiological storage disorders."

A critical piece of evidence was commonly cited against using CA technology for Delicious. D. V. Fisher had reported to the 1939 ASHS meeting in Columbus, Ohio that "It has again been suggested in this experiment that storage of Delicious in atmospheres containing carbon dioxide results in earlier development of mealiness than in air checks." (20, p. 461) Fisher's experiments had been performed in 1937 at Iowa State College, where Gerhardt (Ph.D., 1928) and Allen (M.S., 1913) had been trained, but now he reported from the Dominion Experimental Station in Summerland, British Columbia. Fisher's 1939 report was cited even in the experiment station bulletin by Smock and Van Doren in which they urged "As a result of [their] one-year study with one atmospheric combination, it might be concluded that Delicious did not respond markedly to controlled-atmosphere storage." (21, p. 15)

But during the 1940's and 1950's, the USDA postharvest research group in Wenatchee never undertook commercial scale experiments to test the CA response of Delicious. Van Doren reported in 1958 "We [Washington State University's Tree Fruit Reserch Laboratory] have two CA chambers of 1600 bushels each for experimental purposes...[and]... There is one 20,000 bushel CA storage at the Marley orchard in Yakima in which Goldens and Delicious are stored." (22, p. 186) The USDA did not have comparable facilities to test northwestern varieties. However, Gerhardt, Smith, Schomer, and Sainsbury were openly skeptical of the additional benefits of CA for Washington apples which had been handled "properly".

Apparently, a rivalry between the USDA postharvest research group and Washington State University researchers had developed over the potential for CA in northwest apple storage. The significance of this contest in affecting the adoption of CA technology in Washington is difficult to appraise objectively; but, by 1966, Smock was convinced enough to respond in the "debate among scientists as to how much good CA

storage does for Delicious and Golden Delicious." In the inaugural volume of ASHS's HortScience, Smock rebutted "A USDA report states that CA storage offers no advantages if air-stored fruit has been handled equally well. Reserch in Massachusetts, New York, Virginia, and Michigan have shown advantages for CA storage with these varieties. In 1964-65 there were 2.5 million boxes of Delicious in CA storage in the state of Washington alone." (23, p. 14) In 1979, Smock discussed the "Contrary evidence...presented by the U.S. Dept. of Agriculture Laboratory in Wenatchee, Washington...In spite of this 'damned with faint praise' by all these workers [including two British Columbia researchers], 21 million bushels of Delicious and Golden Delicious has shown favorable responses to CA." (24, p. 305) The fact that CA storage was being adopted at increasing rates in all major apple producing states was assurance enough for Smock that the technology had benefits for the major varieties of apple.

Smock did not present his research to the Washington State Horticultural Association during the 1940 to 1960 period, perhaps because it was professional courtesy to not appear to intercede in Van Doren's attempts to gain industry and scientific support for CA. When Smock did finally appear on a Washington panel in 1963 to discuss the prospects for CA storage, he was told at the last minute not to mention favorable prospects for Delicious. (25)

A significant feature of the debate over whether Delicious would benefit from CA technology is the conspicuous lack of thorough testing in commercial-sized trials. The USDA group preferred to measure the benefits from improved traditional techniques and relegate the benefits of CA to certain "English" and eastern varieties rather than build the necessary facilities and devote scientific resources to adapting the technology to Washington conditions. Van Doren, on the other hand, recommended CA storage without publishing detailed scientific results to back up his claims. Van Doren did advise a M.S. student in 1949-50, who apparently experimented with CA treatments of Delicious and Golden Delicious apples in Washington, but the results did not appear in any scientific journal nor were they generally acknowledged by the USDA or state university researchers. Smock, with the first commercial-sized experimental CA storage rooms, demonstrated the benefits of CA for apples important to the east but never got involved in solving the problems of adaptation in the west. (26)

Conclusions

In an ironic bit of forecasting, Edwin Smith stated in 1945 that "It is rather depressing...to contemplate that at the present rate of progress it will be at least 20 years before the apple industry will be putting into full use the results of research already secured." (27, p. 111) Smith was not referring specifically to CA storage for apples, but coincidentally it was 20 years from publication of research by Allen and Smock before Washington adopted commercial CA technology. It took less time for the New England states, Michigan, and New Jersey partly because the benefits for their varieties had been clearly and scientifically established by Smock and his students. But Smock had learned of the potential of CA from Frank Allen in California, and Allen had known

about it in Washington as far back as 1920. Overholser, Head of the Horticulture Department at Washington State College from 1930-1945, had known about the potential of CA from Kidd and West and his own research before going to Washington in 1930. Perhaps the irony is not surprising when the relationship among state and Federal research priorities is considered. Scientists have the incentive to solve problems that affect their constituents, and Federal postharvest fruit research tended to focus on interstate problems, for example, transportation. State-funded research tended to help local organizations, especially growers. In the case of Washington growers, production problems were somewhat separated from storage by the organizational structure of the industry. In New York, Smock concentrated his program on the problems of storage disorders of McIntosh, and CA technology was fortunately most successful with this and other eastern varieties. In Wenatchee, Washington, the USDA research group focused on different problems than the state researchers, but with their proximity and the requirement for a close industry relationship, it was natural for differences of opinion to become conspicuous.

Economic conditions in the 1940's and 1950's contributed to uncertainty about recovering added costs of installation and management necessary to receive the benefits possible from CA. The technological capability had clearly been shown to be beneficial for certain varieties by 1940, but the problems of adaptation to local conditions took time to solve through experimentation. In the cases of New England, Michigan, and Virginia, the experimental work was carried out in the 1940's and early 1950's largely by Smock's graduates at the state universities, not by the USDA. Dewey and Southwick, Smock's former students at Cornell, took only three or four years to convince growers to try CA technology. Washington had Van Doren back by 1947, but took ten years before experimenting in comercial situations while the USDA research group in Wenatchee was advocating improvement of traditional methods.

The adoption of CA technology in Washington coincided with the retirement of Fisk Gerhardt in 1957 and the growing recogniton of Smock's leadership in developing CA in the eastern states. By then Van Doren had been superintendent of the Washington State University Tree Fruit Research Laboratory for six years. Given Van Doren's enthusiastic support for CA technology, his experience with research and demonstration in New York, and the six years of apparent influence over research and extension in the Washington fruit industry, Washington's delay in adoption may have been caused by conflicting advice from the USDA researchers. However, it is probably overstating the influence of the scientific dispute to attribute Washington's late entry on this factor alone. Economic factors, such as seasonal price patterns and varietal and marketing strategies, apparently influenced the initial decision to adopt CA technology. These economic differences, in turn, may have affected the research priorities of the different groups and contributed to staging the debate.

Increased plantings of Delicious apple trees in the 1950s led Washington to compete with CA-stored apples from eastern states, and expert advice about the potential benefits of CA technology became uniformly more favorable in the late 1950s. By the early 1960s, eastern

New York, Michigan, Massachusetts, Maine, Vermont, and Connecticut marketed over 90 percent of their fresh apples after April from CA storages. With only 30 percent of its post-April storage in CA, Washington was clearly a late adopter, but with rapid installation during the late 1960's, they have come to lead the United States in CA storage capacity.

Notes

1. The requirements for a CA storage included lowering the oxygen in a refrigerated room from the normal 21 percent to less than 5 percent and raising the carbon dioxide from 0.03 percent to as high as 7 percent, balancing the remainder with nitrogen (Dalrymple, Dana G., "The Development of Controlled Atmosphere Storage of Fruit." Division of Marketing and Utilization Sciences. Federal Extension Service. United States Department of Agriculture. January, 1967. p. 1) To maintain these mixtures for long periods (up to 6 or 7 months after harvest) required building a completely sealed refrigerated room or converting existing space, installing scrubbers to counter the natural build up of carbon dioxide from fruit respiration, and closely supervising the daily conditions (1 to 2 hours per day). See Appendix Table 1 for 1950-1960 CA holdings by state. In 1987, the U.S. apple industry stored about half of its fresh-market crop in CA, and over 90 percent of the post-April marketings came from CA. (International Apple Institute, AppleNews and Special Letter, December and May issues.) The Internatioal Apple Institute (IAI, before 1971, known as the International Apple Association) began publishing member data on CA holdings in 1957. The IAI is the only source for detailed storage data by state, variety, and month.

2. Dalrymple, who studied as an undergraduate at Cornell University under Smock, traces the early research and development of CA through periods of "gestation" (1820-1915), government research (1928-1940), and commercial application (1940-1966). (Dalrymple, Dana G., "The Development of an Agricultural Technology: Controlled-Atmosphere Storage of Fruit." Technology and Culture. 10(1969):35-48.

3. Smock, R. M., "The Possibilities of Gas Storage in the United States." Refrigerating Engineering. 36(1938):366-368.

4. Todd, L., "Robert M. Smock: An Oral History." Cornell University. November, 1984

5. Allen, F. W. and R. M. Smock, "Carbon Dioxide Storage of Apples, Pears, Plums, and Peaches." American Society for Horticultural Science, Proceedings for 1937. pp. 193-199.

6. Smock acknowledges Van Doren's assistance with the mechanical difficulties and admits to having had no talents in this area. (op. cit., note 4.) The credit for being a pioneer in CA and his philosopy for work are detailed anonymously in "Reported Deaths," HortScience. 21(1986):1254.

7. For a review of developments in the U.S. apple industry, the literature has little of critical value. A compilation of state accounts of the fruit industry is History of Fruit Growing and Handling in the United States of America. Fisher, D. V. and W. H. Ushall, (Ed.) Regatta City Press, Ltd. British Columbia, 1976. Marketing problems in Washington and Oregon are discussed in Ellison, Joseph W., "Marketing Problems of Northwest Apples, 1929-1940." Agricultural History. 2(1952):102-115. Washington's and New York's production and marketing practices in the 1930's are compared in Overholser, E. L., "Production and Marketing Problems of Apples in the States of Washington and New York Contrasted." Washington State Horticultural Association, Proceedings for 1936. pp. 87-101. For a post-World War II review of changes in a major state, see Kessler, G. M., "A History of Fruit Growing in Michigan." Annual Report of the Secretary of the State Horticultural Society of Michigan for the year 1970. pp. 114-147.

8. United States Department of Agriculture, Agricultural Statistics. Various issues. The 1910-14 average crop sizes were U.S. total, 199 million bushels; Michigan, 12 million; New York, 34 million, Washington, 6.4 million. (United States Department of Agriculture, The Agricultural Outlook. Farmers Bulletin 645, Table 4.) See Appendix Table 2.

9. United States Department of Agriculture, Commercial Apples: Production by Varieties. Crop Reporting Board. Annual issues.

10. Washington's share of the Chicago market dropped from 58 percent in 1953 to 43 percent in 1957, while New York's and Michigan's combined share rose from 26 percent to 39 percent (United States Department of Agricultrue, Agricultural Marketing Service, Fruit and Vegetable Unloads, annual issues). Competition in the fresh apple market between west (mainly Washington) and east (mainly New York) was manifest in real economic and perceived terms. E. L. Overholser, a Cornell graduate, could say from experience that Washington was different from the "so-called 'barrel states,' which perhaps would be dominated by New York." And "The Delicious in the Hudson Valley [of New York] apparently does not attain the high quality as when grown in Central Washington" (op. cit., note 7, p. 93) However, McIntosh from New York consistently brought a premium price compared to the average, even before CA technology improved its quality in the late-season months (Woodin, M. D., "Changes in the Prices of Apples and Other Fruits." Cornell University Agricultural Experiment Station Bulletin 773. 1941.).

11. The costs of regular and CA storage were compared in Louden, James E. and C. H. Zuroske, "Economics of CA Storage of Washington Apples." Washington State Horticultural Association, Proceedings for 1953. pp. 77-84. Louden and Zuroske found that "...in past years limited volumes of apples similar or poorer in quality than that of expected controlled atmosphere stored Washington Red Delicious were marketed in the latter months of the marketing season at significant price premiums. Had controlled atmosphere stored Washington Red Delicious been available during these years, it is thought that they also would have returned price premiums...Thus we conclude, that in situations where technical aptitudes and managerial personnel are present, and where the conversion of existing storage facilities to controlled atmosphere storage can be

integrated into the over-all storage and marketing operation, controlled atmosphere storage of Washington Red Delicious was considered to be economically feasible." (21, pp. 82-84)

12. The legislative history of CA regulations is undocumented. For a brief mention of developments in New York, see Dalrymple, Dana G., op. cit., note 1, p. 23. For questions about Washington's proposed CA regulations see "Questions Answered by Ray Kern, Washington State Horticultural Association, Proceedings for 1961. pp. 93-95. The USDA apple grades underwent their first overhaul in 20 years in 1951, when a new Extra Fancy grade was added "to provide a classification for premium fruit" with more color and fewer blemishes than the old Fancy grade. (Nold, Truman, "The New Apple Grades." American Fruit Grower. 71(1951):20-22.

13. Smock, R. M., "Controlled Atmosphere Storage for Better Apples." Annual Report of the Secretary of the State Horticultural Society of Michigan for the year 1956. pp. 55-57. According to Dr. Warren Stiles, hired at Rutgers University to develop postharvest technology, Smock pioneered the early commercial application of CA technology in New Jersey, around 1956. (personal communication, Department of Pomology, Cornell University, April 28, 1988) See, for example, in the New Jersey horticulture industry monthly: Smock, R. M., "Controlled Atmosphere Storage for Apples." Horticultural News. 37(1956):2982.

14. Van Doren, A., "Physiological Studies with McIntosh Apples in Modified Atmosphere Cold Storage. American Society for Horticultural Science, Proceedings for 1939. pp. 453-458.

15. Gerhardt, Fisk, Edwin Smith, and Harley English, "Effects of Carbon Dioxide on Apricots and Peaches Under Simulated Transit Conditions." American Society for Horticultural Science, Proceedings for 1940. pp. 243-248.

16. An example of the debate fora, besides the annual meetings of the Washington State Horticultural Association, is the Washington fruit industry's Research Foundation which published Apple Research Digest. In the August 1957 edition, G. F. Sainsbury and Harold Schomer wrote "In this last year's operation with our controlled atmosphere storage, lots of fruit from CA showed marked superiority to similar lots of fruit held in the regular commercial storage whereas experimental [CA] lots showed little difference from similar fruit harvested under optimum conditions in regular refrigerated storage. From this we conclude that commercial storage operation is falling considerably short of the optimum." (p. 2) The USDA research group also used Federal government reports to deliver their judgements. See: Schomer, H. A. and G. F. Sainsbury, "Controlled-atmosphere Storage of Starking Delicious Apples in the Pacific Northwest." USDA, Agricultural Marketing Service, AMS 178. March 1957 and Olsen, K. L. and H. A. Schomer, "Oxygen and Carbon Dioxide Levels for Controlled Atmosphere Storage of Starking and Golden Delicious Apples." USDA, Agricultural Marketing Service, Market Quality Research Division, MRR 653. 1964.

17. Van Doren, A., "The Storage of Golden Delicious and Red Delicious Apples in Modified Atmospheres." Washington State Horticultural Association, Proceedings for 1952. pp. 91-96.

18. Gerhardt, Fisk and G. F. Sainsbury, "Soft Scald and Its Control in Delicious." Washington State Horticultural Association, Proceedings for 1952. pp. 97-99.

19. Gerhardt, Fisk and Edwin Smith, "Physiology and Dessert Quality of Delicious Apples as Influenced by Handling, Storage, and Simulated Marketing Practice." Washington State Horticultural Association, Proceedings for 1945, pp. 151-172.

20. Fisher, D. V., "Storage of Delicious Apples in Artificial Atmospheres." American Society for Horticultural Science, Proceedings for 1939. pp. 459-462.

21. Smock, R. M. and A. Van Doren, "Controlled Atmosphere Storage of Apples." Cornell University Agricultural Experiment Station Bulletin 762. June 1941.

22. Van Doren, A., "Controlled Atmosphere Storage of Apples. Washington State Horticultural Association, Proceedings for 1958. pp. 185-186.

23. Smock Robert M., "Recent Advances in Controlled Atmosphere Storage of Fruits." HortScience. 1(1966):13-15.

24. Smock, Robert M., "Controlled Atmosphere Storage of Fruits." Horticultural Reviews. 1(1979):301-336.

25. Smock (op. cit., note 4, p. 20) remembered "...going to a panel discussion out there at their [Washington's] horticultural meetings [probably in 1963]...And as we just started the discussion of the panel, one of the USDA members of the panel turned to me and said, 'Say nothing good about CA storage for Delicious.'"

26. The cultural, genetic, and climatic causes of variable apple quality and the high costs of commercial-sized CA rooms limited the possibilities of adequate replication for a single year's experiments, thus the necessity for multiple year trials. The only publication of Van Doren's early experiments in Washington is apparently Budiselich, E. T. and A. Van Doren, "Progress Report on Apple Storage Experiments." Western Fruit Grower. 4(1951):11-12.

27. Smith, Edwin, "Why are Washington Apples so Frequently not Delivered to the Consumer in Satisfactory Condition." Washington State Horticultural Association, Proceedings for 1945. pp. 109-112.

Appendix Table 1. December 1 holdings of apples in controlled atmosphere storage, by state, 1950 to 1960. 1/

State	Year					
	1950-to-1955	1956	1957	1958	1959	1960
	Thousand bushels					
Maine			98	182	195	203
New Hampshire			70	139	162	190
Vermont			44	48	62	122
Massachusetts			193	440	471	486
Connecticut			29	53	74	53
New England	264	163	434	863	964	1,053
Western New York				54	94	108
Eastern New York	2,046	734	1,130	1,564	1,676	1,660
New Jersey		22	20	50	79	93
Virginia					12	
Michigan		31	145	538	646	950
California				56	262	260
Oregon				50	46	
Washington				25	142	474
Total	2,308	949	1,729	3,200	3,922	4,598

1/ The 1950-1955 holdings are 6-year totals.

SOURCE: International Apple Institute, Special Letter, 1959 and 1960, op. cit., note 1

Appendix Table 2. Apple production: Selected states and U.S. total, 1940-1959

Year	Michigan	New York	Washington	Other	U.S.
			Thousand bushels		
1940	6,298	12,865	25,800	66,611	111,574
1941	8,000	16,302	26,804	70,954	122,060
1942	9,234	18,997	27,339	72,703	128,273
1943	5,888	13,602	23,000	46,560	89,050
1944	7,300	15,795	31,600	66,571	121,266
1945	1,250	2,160	26,530	36,746	66,686
1946	7,560	15,116	32,710	63,515	118,901
1947	6,400	15,045	33,400	58,047	112,892
1948	4,830	11,750	25,760	46,990	89,330
1949	13,800	20,090	30,700	69,719	134,309
1950	8,700	18,700	34,200	62,169	123,769
1951	11,500	18,000	18,300	63,999	111,799
1952	7,400	12,750	21,700	52,235	94,085
1953	10,500	15,000	23,500	46,778	95,778
1954	7,600	19,000	22,000	63,278	111,878
1955	8,300	19,700	24,600	53,663	106,263
1956	12,000	14,100	17,700	57,515	101,315
1957	10,400	16,000	29,800	63,058	119,258
1958	12,700	22,000	27,500	65,285	127,485
1959	13,500	20,000	21,700	71,647	126,847

SOURCE: United States Department of Agriculture, (1940-43, Agricultural Statistics, various issues); (1944-48, Statistical Bulletin No. 114); (1949-59, Statistical Bulletin No. 292)

Appendix Table 3. Apple prices: Freight-on-board averages for selected states and months, 1946/47-1957/58 seasons

Season	Michigan			New York			Washington			U.S.		
	Nov.	Feb.	May	Nov.	Feb.	May	Nov.	Feb.	May	Nov.	Feb.	May
	Dollars per bushel											
1946/47	2.00	2.25	2.75	2.30	2.40	2.85	2.40	3.10	3.35	2.35	2.78	3.18
1947/48	2.00	1.95	1.25	2.05	1.80	1.30	2.40	1.90	2.45	2.17	2.00	1.91
1948/49	2.40	3.00	3.15	2.30	2.60	3.50	2.75	3.45	3.00	2.25	2.97	3.14
1949/50	1.10	1.40	2.00	1.30	1.35	2.10	1.70	2.30	3.05	1.43	1.78	2.40
1950/51	2.25	2.10	2.00	1.50	1.65	1.40	2.25	2.10	1.80	1.96	2.07	1.84
1951/52	1.80	2.00	2.50	1.50	1.90	2.25	3.60	3.70	4.80	2.06	2.36	2.84
1952/53	2.85	3.10	3.85	2.90	2.85	2.95	4.00	3.80	4.40	2.82	3.19	3.42
1953/54	2.20	2.55	3.10	2.70	2.95	3.60	4.10	4.05	3.90	3.02	3.27	3.44
1954/55	2.70	2.65	2.70	2.20	2.15	2.35	3.80	3.95	4.10	2.81	2.94	3.06
1955/56	1.85	2.10	2.75	1.75	1.95	2.25	3.30	3.30	3.60	2.48	2.74	3.41

SOURCE: United States Department of Agriculture, Agricultural Prices, monthly issues