relative to salt. Most users reported that it worked adequately but not quite as effectively or in quite the same manner as salt. Unlike salt, it did not produce significant surface melting and flowing brines that melt ice from top to bottom. CMA worked best when applied at the outset of a storm, before significant snow and ice accumulation. When applied early, it was able to mix with the falling snow and prevent the formation of snowpack and the bonding of ice to the pavement. It performed best when accompanied by plowing or traffic activity, which was important for removing loose snow and ice from the pavement. In situations characterized by light traffic and limited plowing or when ice and snowpack were allowed to accumulate, its performance was often reduced. Whereas salt also worked best when accompanied by traffic and plowing, its ability to produce surface melting made traffic activity and early application less important factors.

Users also reported that CMA performed somewhat less effectively than salt at lower temperatures and in certain types of storm conditions. Although slightly slower acting, its performance was comparable with salt's at storm temperatures above −5°C (23°F).[1] At these temperatures, it started to penetrate light snowpack within 15 to 30 min of salt (salt acted almost immediately). When used during colder conditions, however, CMA's relative effectiveness diminished. For instance, at storm temperatures between −10°C and −5°C (14°F and 23°F), its performance was frequently judged inadequate. It was also described as less effective than salt during freezing rain and storms characterized by light, fluffy snow.

Most users indicated that between 20 and 70 percent more CMA than salt was required during the winter. Spreader units were typically calibrated to release about 50 percent more CMA than salt, although CMA was often applied less frequently during longer storms. Several highway agencies found that early application (i.e., at the outset of the storm, before significant accumulation) was critical and helped improve its effectiveness and reduce the amount used. As might be expected, highway agencies with the most experience using CMA developed more effective and efficient use strategies that helped reduce application quantities over time.

The general conclusion reached by most users was that CMA's handling and spreading characteristics are comparable with those of salt. No major problems were identified. The most frequently cited drawback was its tendency to cake and stick to spreading equipment, which required operators to periodically chip or knock loose accumulations between applications and during cleanup. Generally, however, this problem was described as only a minor inconvenience. The field reports indicate that dusting and blowing were less troublesome than reported in pre-1985 field trials, though in many cases protective dust masks and truck covers were still required during handling and spreading activities.

CMA had to be kept dry during storage, usually in enclosed and well-ventilated shelters. Because most tests were conducted using small quantities, users could not project storage requirements for prolonged and large-scale use. CMA is less dense than salt, taking up about 60 percent more space per ton. As a practical matter, therefore, the effect of large-scale use on existing storage and truck capacities is likely to be an important consideration to users. On the basis of product density differences alone (not including differences in tonnage requirements), at least 60 percent more storage and truck capacity would be required if CMA is used as a more general replacement for salt.

Health and Environmental Effects

The only known effect of CMA on humans is its tendency to create a nuisance dust during storage and handling that may require the use of dust masks and well-ventilated storage and loading areas. Studies indicate that CMA is likely to have negligible effects on drinking water. Because it is biodegradable and exhibits poor mobility in soils, it is less likely than salt to reach groundwater. CMA has demonstrated no detrimental effects on soil compaction or strength, and it may increase the fertility and permeability of some roadside soils. In preliminary environmental evaluations, the potential for CMA to extract heavy metals from soils was identified; however, results from follow-up studies have not indicated this effect.

Neither irrigation nor spraying with CMA has caused detrimental effects in most common roadside plants tested. CMA is apparently safe for use near most aquatic environments, having produced no deleterious effects on organisms representing the aquatic food chain when tested at concentrations likely to be generated by highway deicing. A concern that remains is the potential for CMA to reduce dissolved oxygen levels as it decomposes. Hence, heavy CMA treatments near small, poorly flushed, or poorly diluted ponds and streams may require special monitoring and further study.

These findings may not apply to CMA derived from feedstocks other than reagent chemicals, natural gas, and agricultural products. Alternative feedstocks, such as municipal solid waste and pulp and paper mill biomass, could introduce contaminants that alter its known environmental effects or create new ones.

Compatibility with Motor Vehicles and Highway Materials

CMA is much more compatible with automotive materials and components than is salt. Virtually all automotive metals, materials, and components that have been tested in laboratory experiments have exhibited fewer negative reactions when exposed to CMA than when exposed to salt. The tendency of CMA spray to adhere to windshields and body parts, which has been reported by some field users, would probably require further study before more widespread CMA use.

Laboratory tests also indicate that CMA is less detrimental than salt to common highway materials, including those used for paving, road marking, and construction. CMA is also less corrosive than salt to exposed steel and other metals commonly used on bridges for applications such as joints, gutters, railings, and beams. Most recent findings indicate that CMA is less corrosive than salt to new reinforced concrete and does not accelerate corrosion of older, chloride-contaminated concrete. However, there is insufficient evidence to determine whether CMA reduces the rate of corrosion of reinforced concrete that is already contaminated with chlorides, which is the condition of many older bridges in the Northeast and Midwest.

Production Costs and Price

CMA is produced by reacting acetic acid with dolomitic lime. Whereas dolomitic lime is abundant and inexpensive, acetic acid is far more costly. Currently, the most economical method of producing acetic acid is by using natural gas as a feedstock. After spending several years investigating alternative processes for producing CMA, FHWA and most states now rely on industry for further development.

Chevron Chemical Company is currently the only commercial producer of CMA. It makes a pelletized product in which the acetate is derived from natural gas. The current price is $600 to $700 per ton delivered to reflect projected full-scale production costs. Various technologies have been explored during the past 10 years to produce CMA less expensively, but no significant breakthroughs appear imminent. Given the uncertain prospects of alternative production technologies and the long-term schedules required to introduce new production processes, CMA prices on the order of $600 to $700 per ton are the only reasonable projections that can now be made.

COST AND USE ISSUES

As a means of identifying some of the important cost and use issues that must be addressed when considering conversion to CMA, three general situations are discussed. First, the use of CMA on a widespread, or systemwide, basis is considered. This is followed by a discussion of a local conversion to CMA, such as in a state maintenance district or in a municipality. Finally, consideration is given to highly selective CMA application, which is essentially how CMA is used today.

Widespread CMA Use

The main reason for considering a large-scale conversion to CMA is to reduce all or most of the indirect costs of salting. Use of CMA as a general replacement for salt would probably result in sizable reductions in certain salt-related damages, such as corrosion of inadequately protected motor vehicles, bridges, parking structures, and roadside objects.

As a practical matter, however, large-scale conversion to CMA would have uncertain effects on many costs related to corrosion protection. For example, in the case of motor vehicles, the continued corrosivity of the highway environment due to atmospheric pollution (e.g., acid precipitation), sea spray, and other highway contaminants would probably result in only partial reductions in vehicle rust protection and its cost. Moreover, if the highly corrosive chemical calcium chloride is still used in large quantities for low-temperature deicing (at temperatures in which CMA is not an effective alternative) and for dust control, manufacturers might forego little, if any, corrosion protection, even in the complete absence of road salt. For similar reasons, widespread use of CMA would result in uncertain effects on corrosion protection of new bridges and parking structures. The abandonment of corrosion protection on new structures (which are designed for 40 or more years of service) would be risky, because of the existence of other corrosion sources and the potential for salt or calcium chloride to be used on the structure in the future (if, for example, funding for CMA was no longer available or CMA was not effective for all deicing conditions).

Widespread use of CMA would benefit aspects of the roadside environment and possibly the quality of drinking water in some communities. Most research indicates that CMA has less severe impacts than salt on the environment and water quality except in certain controllable situations. Because the effects of road salt on the environment depend on the specific site, it is difficult to estimate the specific environmental savings, or benefits, that might be achieved from the general use of CMA.

If a moderate- or large-scale conversion to CMA were made, highway agencies would learn how to use CMA more efficiently and effectively. They would modify equipment and adopt spreading, handling, and storage practices better suited to CMA. Nevertheless, such a conversion would have far-reaching effects on winter maintenance budgets and operations, both during the initial conversion and in the long term. Widespread use of CMA would present operational challenges to highway agencies that are accustomed to salt's greater versatility and better ice-melting capacity. For instance, a potential drawback to widespread CMA use is the need to apply it early during a storm. Highway agencies typically treat primary highways first and secondary roads later, after snow and ice has accumulated. Because CMA is less effective when application is delayed, earlier treatment of all roads might be necessary.

Currently, state and local highway agencies spend about $300 million to purchase the 10 million tons of salt that is spread each winter (Chapter 2). This expenditure, which does not include attendant spreading, handling, and storage costs, represents about one-fifth of the $1.5 billion spent each year on highway snow and ice control. Priced at about $650 per ton, CMA is about 20 times more expensive per ton than salt, which sells for an average of about $30 per ton. The experience of CMA users suggests that at least 20 percent more CMA is required than salt (by weight) during the winter. Accordingly, complete replacement of salt by CMA would result in approximately a 25-fold increase in deicer material costs (1.2 times more CMA tonnage × 20 times higher price per ton). Total spending on deicing material would increase from $300 million to about $7.5 billion per year (25 × $300 million).

By itself, a 25-fold increase in deicing material costs would increase total spending on winter maintenance ($1.5 billion per year) by a factor of about five ($7.5 billion/$1.5 billion = 5). Additional storage space and spreading equipment, as well as changes in deicing practices, would increase expenditures even more, particularly during the initial conversion. CMA is less dense than salt, requiring 60 percent more storage space per ton. This density difference combined with

CMA's greater quantity requirements suggests that nearly twice as much storage space and truck capacity would be required (1.2 times more CMA tonnage × 1.6 times greater volume per ton = 1.92 times more volume per ton of salt replaced). This requirement would translate into additional spending on enclosed storage facilities, spreading equipment, and manpower. As an illustration of the potential magnitude of these costs, the New York State Department of Transportation estimates that existing salt spreading, handling, and storage operations cost about $25 per ton of salt applied and represent about 15 percent of state expenditures on highway winter maintenance (see Chapter 2). A near doubling of these costs would increase existing winter maintenance budgets by 10 to 15 percent.

Local CMA Use

Conversion to CMA on a more limited basis (i.e., a municipality or state highway district) would probably result in some savings in salt-related damage in locations where CMA is used, although not in proportion to the reduction in salt use (e.g., a 10 percent reduction in salt use would probably result in a much smaller reduction in salt-related costs).

The main reason for using CMA in this manner would be to reduce local environmental and infrastructure damage from salt. Local environmental effects and possible savings can only be determined on a site-by-site basis. Local conversion to CMA, however, would result in little, if any, savings in vehicle corrosion and protection costs, because vehicles would still be exposed to salt elsewhere, and relatively small amounts can cause corrosion (see Chapter 3). Local CMA use would probably result in some savings in damage to bridges and other infrastructure. The savings would depend largely on the level of protection and the condition of infrastructure in the locality where CMA is applied. For example, application on bridge decks that are sound and poorly protected from salt might result in sizable reductions in corrosion damage, whereas application on well-protected or salt-contaminated bridges would have less beneficial results. In all likelihood, the savings from reduced salt protection on new bridges and parking garages would be negligible, because of salt-tracking from non-CMA areas and the possibility of salt or calcium chloride being used in the future.

Many of the operational and budgetary issues associated with a local conversion to CMA are similar to those identified in the preceding discussion of widespread use. Highway agencies would be challenged by CMA's limited versatility compared with salt. Considerably more spending on deicing material, equipment, and manpower would be necessary even for local use. For example, a 10 percent conversion to CMA by a state highway agency would increase its total expenditures on deicing material by about 2.5-fold because of CMA's higher price and greater volume requirements (0.10 × 25-fold increase in deicing material costs estimated for widespread use).

By itself, a 2.5-fold increase in deicing material costs, which normally account for about 20 percent of winter maintenance budgets, would increase state spending on snow and ice control by about 50 percent (0.20 × 250 percent). However, conversion to CMA would also require modification of storage, handling, and spreading operations and equipment. Estimates from the previous discussion on widespread CMA use suggest that existing spreading, handling, and storage costs would nearly double in locations where CMA is widely used.

Selective CMA Use

Currently, CMA is used selectively and in small quantities, primarily in environmentally sensitive areas and on new (uncontaminated) concrete structures and highway sections. On the basis of existing information about CMA's deicing performance and cost, the committee believes that such selective applications are likely to be the principal uses for CMA in the future.

Whether CMA should be used in such situations can only be determined on a case-by-case basis, after comparing salt, CMA, other deicers, and other mitigation measures. This is especially true for environmentally sensitive areas, because each roadside has its own unique environment, and valuations of environmental damage vary by location. For instance, CMA is currently used on highway sections in California and Nevada to reduce chloride injury to roadside trees and in Massachusetts to prevent sodium contamination of residential wells. In each of these states, the decision to use CMA was influenced more by public pressure than economic evaluations of the total costs of each product.

Similarly, whether it is appropriate to use CMA on a specific bridge or highway segment to reduce corrosion damage can only be determined on a case-by-case basis. To illustrate some of the factors that must be evaluated by highway agencies when considering the use of CMA, three hypothetical bridge examples are presented in

Table 7-1. Numerous assumptions are required, including the timing and cost of deck repair if salting continues; the quantity of CMA required to achieve acceptable deicing; and attendant CMA storage, handling, and spreading costs. Changes in any of these assumptions, as well as the discount rate employed, have significant effects on cost comparisons. Among the numerous considerations not addressed in the example are effects on nondeck bridge damage, effects on motorists using the bridge, and the cost-effectiveness of other deicers and mitigation measures.

The example indicates that simple generalizations cannot be made about the types of situations in which selective application of CMA might be appropriate.

OUTLOOK FOR REDUCING DEICING COSTS

More than 20 years after the adverse side effects of road salt first came to light, the total cost of salting continues to be high. Major achievements in corrosion protection have helped control some of these costs and are expected to continue to do so in the future. In addition, carefully designed and well-located salt storage facilities and better-managed salting programs should help reduce environmental damage and water contamination.

The efficient use of salt should continue to be an important priority in winter maintenance programs. Demands on highway agencies for fast and effective deicing, however, sometimes result in indiscriminate salting. However, new developments in winter maintenance—including deicer application techniques (e.g., salt prewetting), plowing and spreading equipment, and weather and roadway monitoring (e.g., pavement sensors)—are making these priorities less conflicting. Sodium chloride is likely to continue to be the predominant highway deicer for many years to come. Nevertheless, highway agencies and private industry continue to refine and seek new means of preventing and treating salt's adverse effects, for example, by improving corrosion protection and developing new corrosion repair and treatment methods. Likewise, research continues aimed at reducing salt use by developing anti-icing technology (e.g., chemicals for pretreating roadways to prevent ice formation), improving salt application techniques, and exploring deicer alternatives to salt.

CMA is one of many options available to highway agencies for reducing salt's adverse effects. As experience with CMA increases, knowledge about its use characteristics will increase. The decision to use CMA can be made only on a case-by-case basis, taking into

TABLE 7-1 HYPOTHETICAL USE OF SALT AND CMA FOR HIGHWAY STRUCTURES AND COMPARATIVE COSTS

Approximate Bridge or Viaduct Dimensions[a]	Continued Salting: Present Value Cost[b] ($ millions)				Conversion to CMA: Present Value Cost[c] ($ millions)	
	Early/ High-Cost Repair[d]	Early/ Lower-Cost Repair[e]	Late/ High-Cost Repair[f]	Late/ Lower-Cost Repair[g]	High Quantities of CMA[h]	Low Quantities of CMA[i]
1 mi (500,000-ft² deck)						
5% discount rate	12.9	6.6	7.8	4.0	5.6	4.0
10% discount rate	7.9	4.0	2.8	1.5	2.9	2.0
½ mi (250,000-ft² deck)						
5% discount rate	6.5	3.4	4.0	2.1	4.7	3.3
10% discount rate	4.0	2.0	1.5	0.8	2.4	1.7
¼ mi (125,000-ft² deck)						
5% discount rate	3.3	1.8	2.1	1.1	4.2	3.0
10% discount rate	2.0	1.1	0.8	0.4	2.2	1.5

NOTE: Hypothetical structures are on Interstate highway with six 12-ft lanes and two 9-ft shoulders (90-ft-wide deck).

[a]Assumes that structures are poorly protected against corrosion and are not yet critically contaminated with salt. Also assumes that calcium chloride is not normally used.

[b]All costs are calculated for 50 years and discounted to present value using annual discount rates of 5% and 10%. Assumes a direct cost of salting of $55 per ton, including material, spreading, handling, and storage costs. Assumes that the bridge deck and 1 mi of approach highway in each direction are salted at an annual application rate of 15 tons per lane-mi.

[c]All costs are calculated for 50 years and discounted using discount rates of 5% and 10%. Assumes direct CMA costs of $700 per ton, including material, spreading, handling, and storage costs. Includes the cost of applying CMA to the bridge deck plus 1 mi of approach highway in each direction. Assumes that no significant amounts of salt will be carried to the deck from beyond the 1-mi approaches. Assumes no chloride deicers (including calcium chloride) are used on the deck. Assumes no rehabilitations or other major repairs will be required during the 50-year period.

[d]Assumes that major deck rehabilitation will be required after 10 years. Rehabilitation involves total replacement of concrete and installation of an effective salt protection system at a cost of $40/ft².

[e]Assumes that major deck rehabilitation will be required after 10 years costing $20/ft².

[f]Assumes that major deck rehabilitation will be required after 20 years costing $40/ft².

[g]Assumes that major deck rehabilitation will be required after 20 years costing $20/ft².

[h]Assumes that 1.7 times more CMA (by weight) will be applied than salt (i.e., 25.5 tons per lane-mi).

[i]Assumes that 1.2 times more CMA (by weight) will be applied than salt (i.e., 18 tons per lane-mi).

consideration other deicers and mitigation measures available. CMA's use and acceptance is likely to depend in large part on the progress made in these other areas.

NOTE

1. CMA does not ionize as readily as NaCl, thereby slowing initial action. In addition, because acetate ions are larger than chloride ions, the rate of diffusion into the liquid film surrounding ice is slower, which further delays reaction time compared with NaCl.