becomes the handmaid, or better still the adviser, of the state.

More than a quarter of a century ago it became evident that stone fortifications are worse than useless in the presence of modern armaments; but as a people we have yet to learn that the stone building which is about to be dedicated is one of the bulwarks of the nation. The executive branch of our government has learned it partially; the legislative branch not at all. I look forward with hope—and even confidence—to the day when science will be in in the saddle, not for science's sake so much as for America's sake.

And it is precisely in Palmer Hall that young men and young women are going to learn that accuracy of speech and thought which is at once the first step in morality and the best preparation for action. *Here, if anywhere,* will be acquired productive scholarship.

Could we have with us the man whose life and character is celebrated to-day throughout this broad land no one would be more enthusiastic than he in applauding the purposes of this institution and in acknowledging our national indebtedness to this and to similar foundations.

Upon the teacher of science, perhaps, above all others falls the duty of insisting with Lotze that 'while the scientific method may not be the royal road to salvation it will at least keep us from straying very far from the path.'

And when on the morrow Old Glory is raised above this beautiful structure let us salute her as marking one of our national defenses.

Henry Crew.
Northwestern University.

THE SCIENCE OF SMOKE PREVENTION.

Perhaps a better statement of the subject would be 'The Science of Perfect Combustion,' for perfect combustion is attended by no visible smoke. It is always best in a discussion of this kind to define terms before making statements. The Century Dictionary says that smoke is 'the exhalation, visible vapor, or material that escapes or is expelled from a burning substance during combustion' while the Encyclopedia Britannica states that 'Usually the name smoke is applied to this vaporous mixture discharged from a chimney only when it contains a sufficient amount of finely divided carbon to render it dark-colored and distinctly visible.' For us who live in the soft-coal belt the definition may be further narrowed down, for when we say smoke we mean the densely-laden fumes from the combustion of soft coal which deposit thick layers of soot on all exposed surfaces. The smoke from hard coal, coke and wood is so innocuous compared with that just mentioned that it may be entirely disregarded in the discussion.

The occasional production of dense black smoke is peculiar to that group of fuels known as hydrocarbons, of which the more common are the petroleums and bituminous coal. The combustion of hydrocarbons seems to be always complete at first. If one watches the slow burning of a lump of cannel in the open grate he will see a whitish or yellowish vapor expelled from the coal by the gradual heat of the fire. This is the carbon and hydrogen combined which is distilled by the heat and leaves behind the free carbon as coke. While the escape of this vapor unburned represents a distinct loss of heat, the vapor is not smoke as we understand it. It does not deposit soot and will not stain or disfigure surfaces in its path.

As the heat increases and air is supplied the vapor ignites and burns with a yellow flame showing the presence of solid particles. If the temperature remains high and the air supply continues, the combustion is complete and the colorless carbon dioxide and water vapor pass up the chim-

ney. If, however, the burning gas becomes chilled by contact with the relatively cool bricks of the chimney back or if insufficient air is supplied, the yellow flame becomes red and dingy, while particles of finely divided carbon are deposited on the adjacent surfaces or whirled away up the chimney.

The ordinary coal-oil lamp is one of the best illustrations of perfect combustion and consequent smoke prevention. The heated gases rising in the chimney produce a draft, and fresh air is continually drawn in at the bottom through the hot gauze, which warms and divides it so as to insure thorough mixing with the gases from the burning oil. Turn up the wick and the flame becomes smoky—too much hydrocarbon for the air supply. Raise the chimney slightly from the bottom and again there is smoke —too much air at too low a temperature, which chills the flame. Insert a cool metal rod into the chimney and soot is deposited on it—chilling of the flame again and disengagement of the carbon, while the hydrogen continues to burn.

And thus we may learn of the three requisites for good combustion; enough air, a sustained high temperature and a thorough mixing of the gases. The last two are so important that it is entirely possible to have an excessive supply of air and dense black smoke at the same time.

Having thus decided upon the conditions which promote good combustion and prevent smoke, it remains to determine how they may be realized in practise.

It may be said at the outset that it is entirely possible for a good fireman with his shovel, a pile of soft coal and an ordinary flat grate, to so fire a furnace as to make practically no smoke. It may also be said that this is highly improbable and that such a man would command higher wages than are usually paid to firemen.

The best method of hand firing consists in first maintaining as uniform a rate of combustion as possible by putting on coal often and in small quantities; and secondly by varying the air supply to suit any lack of uniformity which may exist. This is known as the one-shovel system of firing and has been successfully used on many of the leading railroads as a means of saving coal and reducing smoke. The nation which shortens its swords lengthens its boundaries and the railroad which shortens its coal-scoops lengthens its mileage per ton. The air supply is usually varied by leaving the door slightly ajar just after coal is put on and then closing it when the coal begins to glow. Several automatic appliances for doing this have been invented and in numerous instances have given good results. The usual plan is to have the device operated by the opening of the fire door at the time of firing.

When the door is opened some simple combination of levers and chains raises the piston of a dash-pot, which in turn lifts a flap in the door itself and opens the valve in a steam-pipe connecting with a system of steam-jets over the door. After the door is closed the flap in the door remains open and so do the steam-jets. The draft created by the latter assists to draw in additional air and the steam mixes it thoroughly with the burning gases. The jets should be directed to the back of the fire near the bridge wall. All this time the plunger of the dash-pot is slowly settling down, dropping the air damper and closing the steam-valve until at the instant when the fresh coal becomes incandescent the air supply is shut off. If the apparatus is made to operate a check-draft in the uptake at the same time the efficiency will be still more improved.

The efficiency of such an arrangement can be clearly represented by diagrams, one showing a cloud of black smoke just as it is cut off by the apparatus being thrown

into gear, while in another are shown the one chimney where the smoke preventer is in use and the three where it is not, about one minute after heavy firing.

The writer has experimented somewhat with air jets maintained by a blower and operated by a dash-pot, but the effect was not so good as when steam-jets were used. When the jets are used intermittently in the manner indicated the waste of steam is small, not over two or three per cent., while the saving in coal is frequently fifteen per cent. Any attempt to solve the problem by admitting a constant additional supply of air through the bridge or side walls has been and will be a failure, since the air supply must be varied as the demand varies.

Hand firing is at best a crude and unsatisfactory method and is gradually being superseded by mechanical means of feeding the coal to the furnace. Mechanical stokers, as they are now called, have two great advantages over hand firing: (1) The uniformity of coal feed which allows a uniformity also in the air supply; and (2) the fact that it is no longer necessary to open the door. Add to these the saving of hand labor and the possibility of handling the coal mechanically from car to furnace, and you have a good argument for the new way.

All mechanical stokers, whether inclined grate, underfeed or chain grate, are intended to feed the coal steadily and uniformly at a speed proportionate to the demand for steam, and by thus maintaining a constant rate of combustion to simplify the problem of air supply. There are at the present time at least ten different makes of stokers which are capable, when properly cared for, of maintaining this uniform combustion in such a way as to prevent smoke and save fuel. Of course somewhat extravagant claims have been made by manufacturers and agents with regard to the economy of these machines. Speaking in a guarded and conservative way, it is safe to say that any of the stokers above referred to can show a saving of from ten to fifteen per cent. over the results of ordinary hand firing.

Perhaps one of the most common causes of smoke is the overcrowding of the boilers. As the amount of work done in a factory gradually increases, new machines are added, more shafting and pulleys purchased, perhaps under pressure from the engineer a new engine is installed. The boiler plant is usually the last to receive attention, although all this time it has been suffering from overload. A boiler gives the best efficiency when worked up to or slightly over its rating; any further crowding will result in smoky fires and waste of fuel. The writer recalls one instance of this kind where an analysis of the ash showed fifty per cent. of free carbon.

Although mechanical stokers will sometimes increase the capacity of boilers, they are liable to overcrowding as well as the flat grate. This results in fires which are too heavy to be successfully handled and in a loss of economy. Overcrowding also increases the repair bill on both furnace and boiler and is on the whole an expensive experiment.

Cleaning fires is another common cause of black smoke, in most cases without excuse. A careful and skilful fireman can keep his fires clean and bright whether on flat grates or mechanical stokers, without any great disturbance of running conditions. Many firemen do not, either because they do not know or because they do not care. The writer has seen a fireman so completely uproot and tear in pieces his fire in cleaning as to necessitate almost a rebuilding. On the other hand, he has seen a skilful man so clean fires on stokers in an efficiency test where the boilers were being crowded to their utmost, that there

was practically no drop in pressure and no perceptible checking of the combustion.

Unskilled and underpaid firemen are responsible for a great deal of the poor economy and the black smoke of our boiler furnaces.

Of the efficiency of mechanical stokers in preventing black smoke there can be no doubt in the mind of any one who has seen them in operation side by side with the old type of hand-fired flat grates.

Their economy can be estimated from the following figures, which are the result not of isolated tests, but of a careful observation covering a period of years. The average rate of evaporation with hand-fired Ohio or Pittsburg bituminous slack is from five to six pounds of water per pound of coal under actual conditions. With mechanical stokers the average rate is from seven to eight pounds of water per pound of coal, and more than this has been obtained under test conditions.

A saving of from 15 to 30 per cent. may be expected from the use of mechanical stokers, and if the cost of steam to run the machine be estimated at 5 per cent. (a liberal allowance) there is left a very comfortable margin.

As the writer is no longer connected with any city government and can not be accused of any warping of judgment, he has no hesitation in saying that he considers the chain grate, as made by the Babcock & Wilcox Co., the Green Engineering Co. and others, as being the most successful solution of the problem of burning soft coal economically and without smoke, so far presented.

The uniform thickness of fire, the steady feed under the boiler and the automatic cleaning are the salient features in an apparatus which is much better than any stoker yet invented.

If one could have a picture of Newburg, that smoky suburb of Cleveland, as it was five years ago, and then again as it is today and as it will be a year from now, when the transition from hand firing to chain grates shall have been entirely completed, there would be no need of any argument on this score.

There is more than one phase in the science of smoke prevention. So far we have considered the strictly mechanical side. There are also the ethical and the legal sides to be considered. Grant that smoke can be prevented, how shall we insure that it will be, without trenching on those rights which every American citizen claims as his? Ethically considered, every one has a right to as much smoke as he wants, so long as he does not incommode or injure his neighbors.

The damage to property and to health from soft-coal smoke is now so generally conceded that no argument on this point is necessary. In other words, the man who allows black smoke to issue from his chimney is guilty of maintaining a nuisance as much as he who allows garbage or foul water to accumulate on his premises.

To quote from the ordinances of the city of Cleveland:

> Sec. 2. That the owner, agent, lessee or occupant of any building or structure of any description from the smoke-stack or chimney of which there shall issue or be emitted such dense or black or gray smoke within the corporate limits of the city of Cleveland, shall be deemed and held to be guilty of creating a public nuisance, and of violating the provisions of this ordinance.

The fact once established by law and precedent that smoke production is a nuisance and that smoke producers may be fined like other law-breakers, it would seem to be a comparatively easy matter to control the evil. Experience has shown that this is not the case and that very few convictions have been made under the law.

The first step that should be taken to regulate smoke production is to make it

incumbent on the owner or builder of every new establishment, where soft coal is to be burned, to install the proper apparatus for burning it smokelessly. It should be necessary for such owner or builder to obtain a permit for setting boilers or furnaces, contingent on proper compliance with the laws regarding smoke abatement, just as it should be necessary to obtain a permit for erecting a building in compliance with the laws concerning safety against fire and accident. This provision is not a hardship and it inures as much to the benefit of the owner as to that of the public.

If every new furnace is thus set in a proper manner and is under the inspection of the proper officers, a rapid improvement will take place. The old will in the nature of things disappear; it is the new which must be the more carefully watched.

In dealing with establishments where smoke is already in evidence both moral and legal suasion must be employed; the former when it will serve, the latter as a final resort. Once convince a man that coal will be saved when smoke is stopped, and the battle is half won. The writer has a record of scores of such bloodless victories.

Before very much can be said to an offender it is necessary to prove to him that he is an offender, and this can only be done by systematic observation covering some little period of time. Whatever system is adopted, the ratings of the various stacks will depend largely on the judgment of the observer and smoke charts are an unnecessary incumbrance. Readings taken at intervals of three or five minutes for several hours, with a grading from one to four in the scale of blackness, will give a fair relative showing for the various chimneys observed and furnish a basis for arguments with the various proprietors.

An observer who has had experience can rate twenty to thirty chimneys in this way from a convenient vantage point. If 4 is taken as dense black smoke and 0 as absence of smoke, a two-hour series of five-minute readings, or twenty-five in all, will give the percentage directly by summation. These two-hour sets can be repeated at different times of day so as to cover the whole period of daylight. In this way the inspector soon becomes thoroughly familiar with each district and knows all the black sheep. A fair comparison made from such ratings will often shame the offenders into better performance.

In rating locomotives a different method must be adopted, as the time of observation is rarely over two or three minutes. For this work a graphic log has been found most reliable. Heavy horizontal lines represent per cent. of black smoke, while vertical rulings represent time intervals, usually from three to five minutes each. The observer counts regularly as he watches the stack and puts down at each interval of time a dot on one of the horizontal lines corresponding with the smoke at that instant. A line drawn through these dots shows plainly the variation in conditions. The other data are filled in as far as they can be ascertained and a copy of this report (made in duplicate by the use of carbon paper) is sent to the proper official of the road immediately. This makes a record which is rarely disputed by the engineer or fireman.

This system as applied in Cleveland had the immediate effect of reducing the smoke from locomotives to less than half the former amount as a result of improved firing, and there has been steady improvement ever since.

In dealing with the smoke problem where the evil already has a firm foothold it is necessary to institute at first an educational campaign, showing the conditions as they exist, the possibility of betterment and the resulting economy. Most smoke-producers are intelligent and reasonable men and will

listen to such arguments and will endeavor to effect improvements.

When such methods fail and the parties interested are obdurate, legal methods should be used. The law or ordinance must be carefully drawn and subjected to the best legal criticism before it is tried. 'It is better never to have sued than to have sued and lost.' But if the ordinance does fail, one has profited by experience and the next ordinance will be stronger.

To sum up the facts and conditions as they have been outlined in this paper it may be said:

(1) That objectionable smoke from soft coal can readily be prevented; (2) that such prevention will result in a higher efficiency and smaller fuel bills; (3) that all new plants should be subject to permits issued by proper city officials; (4) that educational and legal measures combined should be used in cases where the evil already exists; (5) that the control of such work should be in the hands of properly trained engineers who understand the whole subject thoroughly; (6) that the people of each community must see to it that they are protected from this evil as from poor drainage and dirty streets.

CHAS. H. BENJAMIN.

CASE SCHOOL OF APPLIED SCIENCE,
CLEVELAND, OHIO,
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*THE CARDINAL PRINCIPLES OF ECOLOGY.**

WITHIN recent years that old phase of natural history which is concerned with the adaptations of organisms to their environment has become segregated into a distinct department of study under the name of ecology (œcology, biologie). This separation is unnatural, but it is expedient, and it is likely to result in great advances towards that most important, difficult and alluring of scientific ends, the explanation of the raisons d'etre in organic nature.

As now studied by botanists, ecology is concerned mostly with that synthetic phase of the subject dealing with the interpretation of the physiognomy of vegetation, while comparatively little is being done in the analytic phases which investigate particular features, or elements, of adaptation. To such an extent is this the case, in this country at least, that we are accustomed to use the word 'ecology' as a synonym for 'ecology of the vegetation' or 'ecological plant-geography,' a somewhat misleading usage which has been, with some justice, censured. Criticism of the use of the name, however, is of slight account in comparison with the current criticism, unpublished but wide-spread, of the methods of the subject as followed among us. Such criticism arises in part from that ubiquitous human failing which leads us to exalt our own lines of work by invidious reflections upon other lines which we do not, or will not, understand; but it is in large part deserved. Ecological publications in America are too often characterized by a vast prolixity in comparison with their real additions to knowledge, by a pretentiousness of statement and terminology unjustified by their real merits, and by a weakness of logic deserving the disrespect they receive. The subject suffers, I fear, from a phase of the 'get-rich-quick' spirit. These opinions I can express with the better grace when I hasten to admit that, so far as my own few publications are concerned, I am one of the chief of sinners. I believe it is a fact that, despite our numerous ecological publications, the only material advances made in ecology in this country for some years past are in descriptions of vegetation, in which a considerable body of fact has been accumulated. But in interpretation, the very soul of ecology, we have done little

* Read before the Society for Plant Morphology and Physiology at its Philadelphia meeting, December 29, 1903.