ASHALT PAVEMENTS
and the
ENVIRONMENT

By

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ABSTRACT:

This keynote lecture provides an introduction and overview of the challenges and opportunities that face the paving asphalt industry in view of major changes in technology, economy and the environment. The scope and issues for dealing with these challenges are rather wide and complex because the goals, perspectives and expectation for environmental practice and control have changed dramatically over the last couple of decades. Hence the required approach has to be multidisciplinary, based on established scientific concepts and sound engineering principles as well as closely focused.

This presentation provides historical background and facts for dealing successfully with environmental asphalt issues in the past. In addition to environmental protection, the broader scope concerning the environment includes the increasing awareness and concepts for ecology and sustainability. The achievements and the status of current technology are presented for:

1. Environmental protection,
2. Ecology,
3. Sustainability development,
4. Standards, Policies and Environmental Law.

For future direction and opportunities, suggestions are made for new materials and processes based on existing innovative technology such as ‘warm asphalts’ for reducing energy consumption and emissions or improvement of recycling of asphalt pavements to limit the continuing increase in resource consumption with the goal to achieve sustainability.

1.0 Introduction

The first International Symposium on Asphalt Pavements and the Environment carries with it, a message of much greater importance than "drinking together" at a social gathering to exchange opinions, as the original meaning of the name 'symposium' may suggest. The mandate of the speakers as well as all participants is to address, discuss and initiate ideas and projects to deal proactively with environmental challenges and also seize opportunities for innovative solutions. Since the International Society of Asphalt Pavements (ISAP) held a successful workshop on asphalt fumes in Baltimore, Maryland, USA (November 1989) and many environmental, technical and economical changes have taken place since, this symposium is timely indeed, if not already overdue.

You are invited to travel the continuing road of asphalt pavement development from its origin over a century ago to the present and beyond to the future. The scenery varies from a quiet rural road (Fig.1) to a busy, high density highway network (Fig.2).

Figure 1: Scenic Rural Road

Figure 2: Busy Highway Network

The purpose of this journey through time is not only to admire, observe and analyze the progress and success of our industry with respect to scale of economy, but also to determine the impact, interaction and synergism with emphasis on our 'hostal' surrounding or better known by its technical term, the <u>environment</u>. We simply ask the questions:

- What are the issues and challenges?
- Why must we address environmental issues?
- How do we approach and deal with the challenges?
- When do we start?

The key objectives for this opening lecture are:

1. to provide an introduction and overview of the main theme,
2. to inspire and convince the audience by raising critical issues and questions,
3. to summarize achievements and deliver a focused status report, and
4. to outline technological trends and suggest guidelines for future research world-wide.

The goals, perspectives and expectations for environmental practice and control changed dramatically, especially over the last couple of decades. Pollution control in terms of emission and leaching is no longer good enough. While new features, concepts, standards and regulations are being added; planning for a clean, safe, sustainable environment seems more like aiming at a moving target. Considering also, that a multidisciplinary approach such as science, engineering, toxicology, medicine, etc. is required, this undertaking is a quite formidable and challenging task, at least when it is condensed to a 40-minute presentation.

Therefore, we need to closely define and limit the scope and technical terms as well as to focus and concentrate on the most important aspects of asphalt pavements and their impact on the environment. In order to identify meaningful goals and priorities the chosen approach will be based on established science concepts and sound engineering principles. Also, there will be no time for engaging in speculations, political exploitation, equally diverse and often controversial proposals to foster environmental protection, including regulations, financial incentives, investments, etc.

The main content of this presentation is covered in the following sections

(a) "Back to Basics', an account of historical background and facts for dealing with the wider scope of the environment and the development of basic concepts and methodology for addressing new challenges,
(b) 'Achievement and Status' of the required technology,
(c) 'Future Direction and Opportunities', and
(d) 'Summary and Recommendations'.

2.0 Back to Basics

2.1 Historical Background and Facts about Asphalt

The terms 'asphalt' and 'bitumen' are used here interchangeably as they have their roots both in antiquity, i.e. '*asfaltos'* (Greek>*sticky*) and '*bitumen'* (Latin>pitchy). Most paving asphalts are straight-run products made from crude oil by topping the light ends. This means all lighter and medium heavy hydrocarbons have been removed by straight distillation, steam distillation or most frequently vacuum distillation. The remaining black, heavy viscous, sticky, thermoplastic residue is the soft asphalt we are commonly using as paving mix binder. Any modification, by extensive heat-soaking, oxidation, blending with other hydrocarbons or active additives may change the composition and properties, which also may include environmental emissions and leaching. Hence, we usually identify modified paving asphalts accordingly. For environmental studies, we must recognize the importance of the asphalt's 'pyrogenous origin' and composition as well as any subsequent cracking or modification (1). A typical example is the early practice of using asphalt admixtures with coal tar (2), which is known to contain carcinogenic benzopyrene amongst other polyaromatic hydrocarbons (PAH).

Since asphalts are derived from heavy crude oil deposits they can be considered as a valuable resource provided by nature and its long range capabilities to recycle. Such deposits were formed underground from plant and animal remains that have been subjected to millions of years of heat and pressure. The Athabasca Tar Sands in Western Canada are estimated to be the world's largest deposit with an area of 78,000, square kilometers and an estimated quantity of 2700 billion barrels (3). Legend has it that the reed basket in which Moses was set adrift as a baby was coated with asphalt. At that time the Egyptians knew all about the adhesive and water proofing properties of naturally occurring asphalt deposits in the region. In fact, the Babylonians in the valley of the Euphrates River in Iraq were using asphalt as far back as 6000 BC, making it 'arguably' man's oldest engineering material (2, 4).

Today's asphalt recovery by vacuum or steam distillation as described in the definition of asphalt above, produces a material with very low vapour pressure. Therefore, the quantities of emission for hydrocarbons are small for the temperature range relevant for paving applications and a typical Occupational Emission Monitoring (OEL) level is 5 mg/m^3 (5). Asphalts have extensively been used as a sealant in water tanks including aquariums and found to be inert and insoluble in water. Aqueous leaching of poly-aromatic hydrocarbons (PAH) has been shown by Kriech (6) to be below detection limits with a few exceptions. A National Cooperative Highway Research Program (7) carried out at Oregon State University describes the results of laboratory testing a first level screening tool. The asphalt pavements were found to pose no harm to the environment.

Since the introduction of the automobile and the demand for clean and safe transportation grew rapidly, the now existing asphalt pavement network around the globe has contributed tremendously to the development and economic success of many countries. At the same time governments and the industry have also recognized the increasing demand and costs on resources, which resulted in the fact that asphalt roads make up the largest amount of recycled materials worldwide. Actually, in some regions a zero-waste policy already exists.

The great success of asphalt pavements is largely based on the following key features of its origin and industrial development:

- Utilization of large deposits of naturally recycled organic materials
- Experience with the oldest engineering material
- Over 4000 years track record of environmental safe applications
- Performance targeted selection and production of paving asphalts
- Proven recycling technology and the world's largest material recycling operation
- Proven to be and still is the most cost-effective paving material in existence.

2.2 The many faces of environment
The importance of environmental protection, a main thrust of pollution, has in the past fluctuated, but more recently changed to become indisputably a subject of serious and persistent concerns as well as to assume a much wider scope. Focusing on the 'wider scope', we notice a succinct metamorphosis in the concept of environment. Signs of environmental deterioration, such as air and water pollution, extinction of species, and the depletions of resources as well as their causes, including impact of technology and population expansion are increasing. So are also and just as diverse, the proposed answers to these problems, e.g. public education, financial incentives, regulations, etc. Even the terminology has been changing and expanding dramatically since Rachel Carson published her classical environmental book "Silent Spring" (8). At that time, prompted by increasing awareness and concerns, new concepts and descriptions were needed. Added to the traditional terms **environment** (our surrounding) were **ecology** (our home) and then **sustainability** (our survival). These new terms should not be misused or misrepresented as, for example, in the vacation advertisement depicted in Figure 3.

Figure 3: Advertisement for a `green' vacation

Such practice is misleading and counterproductive, especially when practiced by the asphalt pavement industry.

The term 'environment', which described traditionally the complete range of external, physical and biological conditions in which an organism lives, now includes also social, cultural and economic/political considerations for humans. The negative impact of economic activity triggered the term ecology, which was originally coined in 1866 by Ernst Heinrich Haeckel (9). The term refers to the scientific study of interrelationships among organism and between them, living or non-living, as well as their environment (9). Later in 1935, Tansky provided the term 'ecosystem' as a discrete unit that consists of living and non-living parts, interactive to form a stable system (9). 'Sustainability' refers to economic development that takes full account of environmental consequences of economic activities including associated depletion of resources.

The evolving wider scope of our environment is graphically depicted in Fig. 4 and we need to look carefully at all the new faces and increased scope of the environment to assess which are relevant to the asphalt paving industry.

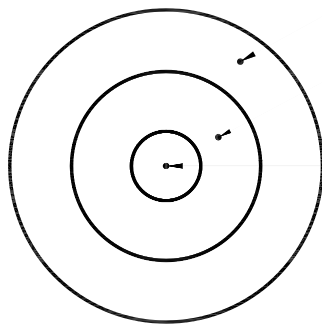

Figure 4: Illustration of the Expanding Environmental Concerns

However, before we start to prioritize and select, we must establish the approach and basis and methodology for decision-making.

2.3 Basic Concepts/ Sound Engineering

Criteria and approach for decision-making, action and problem solving of asphalt pavement challenges must be based primarily on fundamental science and sound engineering principles, e.g. thermodynamics of natural systems, conservation of energy and non-renewable resources, natural balance, equilibrium, etc. rather than on surveys, cross-cultural viewpoints, politics, etc. As our large, worldwide road network and associated maintenance needs increase, so do our demands for natural resources, including energy, air and space. As a result it becomes more and more difficult to maintain a natural balance and equilibrium in our ecosystem, as we perceive it today. Identification, monitoring and assessment of such trends could avoid and reduce negative impacts and their costs. Sound engineering needs to be applied starting with the planning and design phases which should include sustainable development. In order to re-establish equilibrium conditions with an acceptable solution for sustainability, we need to do lifecycle costing for the overall asphalt pavement activities. Any new initiatives such as pavement preservation or saving energy by substituting warm asphalts for hot mix asphalts, work in favour for sustainability. However, in such studies we need to also include any costs for existing as well as newly arising negative impacts including resource depletion.

Where fundamental principles are not yet clearly understood and defined, it would seem prudent to follow the way of nature as an interim solution (not necessarily bio-mimicry methods). After all, nature has an experience advantage for millions of years. “Look deep into nature, and then you will understand everything better (Albert Einstein).

3.0 Achievements and Status

3.1 Overview

In order to discuss the current state and limitations of our knowledge about asphalt pavements and the environment, we have to address the following concerns and key topics as they developed:

1. Environmental Protection
2. Ecology and Ecosystems
3. Sustainability Development
4. Standards, Policies and Environmental Law

The original environmental concerns were mostly **environmental protection** in terms of human health and safety. The concepts of environment expanded with the growing recognition that besides human being other living organisms as well as material resources such as air, water, minerals and energy play an integral part in our environment. A marked interdependence exists and must be respected. This generally accepted development has been described with the technical terms **ecology and ecosystems** meaning the study of living organisms in their habitat. The impact on ecosystems by economic development including resource depletion, have triggered sustainability concerns, namely the recognition that economic development must be a **sustainable development** that takes full account of environmental consequences. The last topic which is the development and introduction of **standards, policies and environmental law,** is an obvious deduction and logic consequence of the first three topics and understandably of considerable interest to the asphalt pavement industry and its stakeholders. A retrospective of the above four key topics is presented in the following sections.

3.2 Environmental Protection, Health and Safety

The first issues were emissions of fumes during asphalt production from crude oil, during use in asphalt pavement construction (i.e. storage and transportation of hot liquid binder, spreading of the hot mix and compaction), as well as pavement maintenance and repair, especially such methods as scarifying with hot open flame and later infrared burners. A close second concern was leaching of potentially dangerous components from in-place pavements into the groundwater and eventually drinking water.

Emission of fumes: When looking at photographs showing fumes coming from early methods of pavement construction at the beginning of the 20th century, pollution concerns can be easily recognized and justified (Figures 5 and 6).

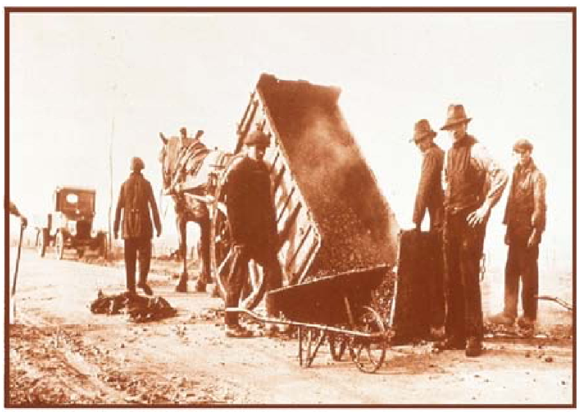
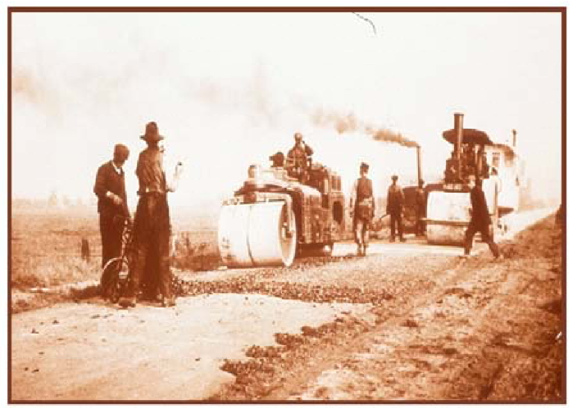

Figure 5: Early Pavement Construction & **Figure 6:** Motorized Pavement Compaction

The irony in this development is that a main reason for a paved road surface was to eliminate dust from the rapidly increasing number of automobiles as well as their speed. The impact and exact nature of the emission were at that time not very well known and defined in part, because paving operation and therefore the emission is largely transient and not easily assessed. However, the asphalt paving industry and governments have recognized and addressed these concerns. By the time I got involved in asphalt research in the mid-1960s, testing methodology and standards for air quality and the occupational environment had advanced sufficiently to conduct sound environmental impact studies. A good example is the Gulf Canada' Mobile Environmental Studies Laboratory or in short known as 'The Environmental Bus' (Figures 7-9).

This unit was used effectively to determine and monitor emissions and leaching from crude oil production at well to the consumer across the country. These environmental studies were not only used to improve the environmental impact but also the efficiency of the field production and refining operation, including the energy consumption.

The ISAP Board of Directors decided in 1988 to stage an ISAP workshop on the possible health effects of Asphalt fumes. Their findings were documented in the ISAP Workshop Proceeding on "Paving Asphalt Fumes: What are the Health Effects", almost 20 years ago by Elaine Thompson and Ralph Haas (10). This workshop was held in Baltimore, Maryland, USA and attended by 53 registrants from Europe, the United States and Canada. They represented a wide diversity of interests and expertise, including engineers, chemists, toxicologists, epidemiologists and industrial hygienists. They came from Federal agencies, asphalt producers and suppliers, contractors, the Asphalt Institute and universities.

Figure 7: Gulf`s environmental bus moving along the paving train

The key objectives of the Workshop were:

1. To review current knowledge and research on the possible health effects of paving asphalt fumes
2. To identify any gaps in this state–of-the–knowledge
3. To discuss proposed regulations, such as the Occupational Health and Safety Administration, OSHA, Vol.53, No. 109, June7, 1988.
4. To develop recommendations for any further data and research needs.

There were 8 presentations from leading experts and also from 4 subsequent panel discussion groups. Examples of the 23 summary conclusions from these presentations and discussion groups include:

Figure 8: Sampling of fumes on the paver

- Emulsions and cold mixes are an alternative to hot mixes but their use is limited to secondary roads. Aggregate moisture is a disadvantage.
- No proven need for worker protection exists, but heavy equipment can be designed so that exhaust is directed away from the operator.
- No special precautions are needed for personal hygiene.
- Regular check-ups for paving asphalt workers would be useful to identify any early respiratory problems and prior worker problems that can affect job functions.
- Asphalt specification changes to recognize working environment could include flash point temperature increase, thin film oven weight loss reduction, and maximum temperature at various points in the operation.
- The widely quoted 'Thayer Project' indicates that asphalt fumes have the potential of causing cancer in animals but the issue of risk to asphalt workers was not addressed.
- A useful future area of study would involve separation of the components used in previous studies.
- The questions of whether sampling devices need to be on the worker of the equipment and how to avoid sample contamination need to be resolved.

- Better worldwide coordination of epidemiology, toxicology, industrial hygiene, engineering controls and other studies is needed.
- Exposure to dust can result in respiratory problems. The co-effects with asphalt fumes are not known. Better information and sharing of knowledge on dust effects would be desirable.
- Temperature limits for paving asphalts are already pretty well defined.
- Paving asphalt workers are among the most highly exposed people to traffic fumes. Improved traffic handling methods to lessen this exposure would be desirable

Figure 9: Dry ice trap for sampling at the stack.

Leachates from Asphalt Pavements: Pollution due to emission was readily recognized due to the obnoxious odours coming off the hot mix. However, leaching from asphalt pavements was of little concern until the 1960s. After all, asphalt products were used since biblical times not only to build roads but also to seal water reservoirs, fountains, aquariums, etc. without any noticeable health effects. This does not necessarily mean as we know now, that leaching didn't take place, but rather that the overall impact at that time was small and unnoticed, based on the existing road-network size and leachate detection limits (11).

3.3 Ecology and Ecosystems

One of the first ecological concerns relating to pavement surfaces is the tire noise coming from a busy highway. The noise created at the pavement tire interface of high speed vehicles are at low traffic volume can be considered transient and labeled as a nuisance. Yet, in case of high volume traffic the continuous noise infringes on the comfort and quality of life for people living in the area. The interest to address this problem with innovative pavement mix designs is evident from 11 papers that were submitted to this symposium on the topic 'Noise Reducing Pavements'. There are of course, other than noise infringements not only to man, but also to other living organism, materials and stable systems, such as safe road crossings, as sharing space and habitat, flow and drainage of water, temperature changes and winter maintenance. Many of these conditions have been addressed and are being continuously improved. Some typical examples are: visible and now also audible traffic-crossing signals, special structures for animal crossings, special provisions for surface water and natural sub-terrain aquifers, and a tunnel for frogs to and from their habitat. If you should ever run into a massive cloud of locust with your car and your windshield wipers stop working, you might just wonder who is infringing on who? Nature can sometimes also be overpowering.

Ecology really gained prominence towards the end of the last millennium, as the world started to recognize and accept that the economy is linked to and depends on the functional integrity of its ecosystem. The main concern is the negative impact of some economic activities. The desired 'ecological economics' is still a struggle for governments and industry, because its value is intrinsic and not conveniently displayed on a marketplace. It appears that policy clarification and development is still needed. The symposium topics 'Roads for Environmentally Friendly Winter Maintenance' and 'Drainage and Water Susceptibility' would benefit from such policy clarification.

3.4 Sustainability Development

The concept sustainability in its contemporary form started in 1983 with the creation of 'The World Commission on Environment and Development' (WCED) by the United Nations (UN). This commission was headed by Gro Harlem Brundtland, former Prime Minister of Norway, and given the mandate amongst other, to propose long-term environmental strategies for achieving sustainable development by the year 2000 and beyond. Based on the commission's deliberations and on what is now known as the Brundtland Report (12), the UN now defines sustainable development as:

> *"The ability to provide the needs of the world's current population without damaging the ability of future generations to provide for themselves. When a process is sustainable, it can be carried out over and over without negative environmental effects or impossibly high costs to anyone involved."*

Based on the above definition, sustainable development is by far the greatest and also the most formidable challenge for the asphalt paving industry that depends largely on the availability of natural resources. The economics of sustainable development requires a balanced budget and borrowing from the future is not allowed. In other words, key factors are the accelerating depletion of natural resources and the negative impact of some economic activities. The cost of both items, namely the uncontrolled depletion of resources and negative impacts should really be factored into the life cycle cost-analysis of our asphalt pavement projects. Since our resources are allocated to competing uses, such implications are important and should not be overlooked. The awareness and concerns of this aspect is reflected in the number of symposium papers on the topics (a) repeated recycling and material resources, (b) low energy asphalt mix production and placing, and (c) roads for energy production.

<u>Recycling of asphalt</u> pavements was already evaluated in full-scale field trials during the 1970s. At this time, the main driving force and objective was to counter increasing costs by reusing aggregates and asphalts. A temporary crude oil and asphalt supply situation was also a consideration. Now the emphasis is on multiple recycling in order to increase the life-cycle and thereby control the ever increasing depletion of resources and, at the same time, through reduction in demand, also the costs. In most developed countries asphalt pavement recycling technology is already advanced. The quantities of recycled asphalt pavements (RAP) are increasing significantly. With the latest technology RAP can be recycled 100% into new pavements and hot mix can be and are routinely designed to accept 20-50% RAP. With a recycling rate of 80%, asphalt pavement is North America's **most recycled product** (13). Multiple and/or continued recycling will have a marked impact on our ability to conserve aggregates, asphalt and energy for the future and thereby supporting the sustainability of asphalt pavements.

<u>Low energy (warm) asphalt mixes</u> have recently staged a major comeback after the original version of 'foamed asphalt' 50 years ago met with some reluctance to get accepted. Fifty years later the energy cost picture has changed dramatically and the investment to develop the required technology is beginning to pay off. The leading incentives and reported benefits are reduced emission, fuel consumption and lower viscosity with improved mix workability, extended paving window, increased proportion of RAP and better performance. Meanwhile, there are 4 different warm asphalt mixing processes in use which are summarized in Table 1.

Table 1: Warm asphalt mixing processes (14)

Process	**Material/System**
Injection of moisture to create foam	• Advera (US) • Aspha-min (Canada, US, EUR) • Double Barrel Green (US) • Low Energy Asphalt(EU, US)
Two stage process (hard-soft asphalt)	• WAM-Foam (Canada, EU)
Viscosity Reduction (flow enhancer)	• Sasobit (Asia, AU, Canada, EU, South Africa, US)
Emulsion (chemical package)	• Evotherm (Canada, US)

Many countries are taking advantage of the available technology and conduct full-scale field trials to evaluate mix production and construction as well as the performance. Field trials throughout the US also included a variety of standard mix designs including Superpave, Marshall, Hveem and several State Highway Departments' mix designs (14). Research projects to study and examine basic performance characteristics of warm asphalts have also been increasing. Of special interest is for instance, the effect of moisture which is left in a mix compacted at low temperature, on adhesion, bond strength, and de-bonding. Other issues include the impact on performance of different types of binder and aggregates, flow enhancing additives, the climate, etc.

'Roads for energy production' is an initiative to utilize solar energy, which is absorbed by the black surface of asphalt pavements. An example for using a road for energy production would be a liquid heat-transfer and circulation system placed under a mountain road which would collect the heat energy in the summer month and store it in a mountain cave or reservoir. The Swiss Project SERSO Plus (sun energy recovery from road surfaces) on the city of Bern bypass A1/6/12 is an excellent example (Fig 10).

Figure 10: Sun energy recovery on Bern by-pass A1/6/12

In the winter the heat-transfer circulation would be reversed to melt the ice and snow during the winter. The size and amount of blacktop asphalt surfaced areas large enough especially in urban areas, to be considered for full-scale heat absorption and transfer. An example is the study carried out by Wm. James in the City of Guelph, Canada (15), to assess the impact of pavement temperature on river water temperature and associated fish population. Related thermal conductivity and volumetric heat capacities as input for evaluation/design models of urban and highway meteorology projects are described by T. Oke in his textbook 'Boundary Layer Climates' (16).

3.5 Standards, Policies and the Environmental Law

With regard to environmental protection, we are well endowed with standards, regulations, policies and environmental laws. Thanks to the dedication, active involvement and leadership of the asphalt industry towards development of standards, regulation and policy, the necessary environmental management has been successful. For dealing with the new challenges brought about by the rather novel concepts of ecology and sustainability as described in the previous sections, the same approach is by all means the way to go, definitely necessary and in the interest of our industry! In most countries the industry is nowadays involved in technology development. Hence the input of correct data, research, and field experience is vital to formulations and decisions of policies and environmental laws.

In the second edition of his textbook 'Environmental Law' J. Benidickson (17) introduces and defines ecosystem protection, ecological integrity, biodiversity, etc. Legal problems concerning the environmental law appear in a large variety of areas and settings ranging from common law to *Charter,* from criminal law to contracts and from international law to statuary interpretation. While the development of environmental law advanced considerably as a tool to environmental protection to cover specific areas such as the Great Lakes water quality, acid rain, protecting the ozone layer and the Kyoto Protocol, asphalt pavements development has not yet specifically been addressed. To maintain in these matters the status of responsible disposition, the industry would seem to benefit from staying abreast of technology and policy developments as a group. Awareness, educational and research programs have been suggested as demonstrated by staging this symposium.

4.0 Future Direction and Opportunities

When we address the future direction and opportunities of our industry, we need to think in terms of 'environmental economics' or more recently 'ecological economics'. We hear much about the negative, human-induced impacts such as pollution, but should also appreciate the natural investment and the benefits that flow from a healthy ecosystem, such as air, water and of course, natural resources. These are shared benefits. Finding optimal, balanced rates of resource extraction and managing common-pool natural resources are destined to be a joint venture and requires a concerted effort. While the application of regulatory incentives such as pollution allowances or tax, have been proposed and may help, I suggest that innovative new as well as existing technology is the direction we should focus on. A selection of novel ideas with examples follows.

4.1 Ongoing R&D for Implementation

The new era of environmental concerns was met by the asphalt pavement industry with a respectable activity of research and development projects to reduce cost, depletion of resources, energy and at the same time emissions during the production and paving process. Old ideas were revived and new ideas appeared and are being developed and adapted as summarized in the previous section. A concerted effort and cooperation to exchange ideas and technology including provisions of adequate funding is needed to move expediently to implementation and to the approval phase. Criteria are: (a) proven long-term performance as in the SHRP era and (b) the challenge/achievement of sustainable development.

One should not underestimate this task nor misapply the term 'sustainable development' and use it as a mere window-dressing for reducing asphalt paving costs to secure, for instance, our standard of living. The quest is to share with future generations the natural resources in order that they also have the ability to provide for themselves. This basically means we need to do lifecycle costing analyses and try to balance the 'ecological budget'. For such a mandate, we may have to do more than just preserve our needed natural resources.

4.2 Focus on the New Direction

A refocusing exercise on the new direction and an adjustment of our vision for the future should help to identify, prioritize and select ideas and research proposals. Priorities for environmental protection concerns with straight-run asphalts are not very high, except that modifications and addition of new materials or chemicals to the base asphalt need to be monitored. However, a key concern is the depletion of asphalt resources and its vigorous competition from the energy market. Therefore, research options that could preserve, extend, rejuvenate or replace asphalt would be considered high priority.

This symposium could provide a forum for such deliberations, as did the ISAP Workshop in Baltimore about 20 years ago, and also initiate, with a representative body and/or technical committee of multidisciplinary experts, the guidelines for the new direction and a strategic work-plan.

4.3 Innovation Ideas Classified

Asphalt Rejuvenators:

Ageing processes including 'age-hardening' of asphalts are generally considered irreversible. However, beginning with the development of asphalt pavement recycling processes, researchers also started to look for suitable rejuvenators. This search never got much beyond cutting back and softening the hardened asphalt binder with softer asphalts.

While testing sulfur–asphalt binders for pavements in 1977 (18), an encouraging observation was made during fatigue testing of sulfur extended asphalt pavement samples. A flexural stress recovery of the original pavement specimen was taking place and indicated that rejuvenation of the sulfur–asphalt binder might be possible. The pavement specimen recovered completely (some surpassed original levels) overnight in strength after the fatigue test was interrupted due to equipment failure. Scanning electron microscopy studies indicated that mono-clinic, needle–like crystals of sulfur deposited in the hairline cracks which were produced by the fatigue test. Since sulfur is uniformly dispersed throughout the paving mix and elemental sulfur has a high vapor pressure, a likely explanation is: "Sulfur vapours could move around and deposit as fibre-like reinforcement in the open spaces left by the fatigue testing". A fine dispersion of sulfur globules in liquid asphalt (2-3 μ dia.) is shown in Figure 11 and SEM (Scanning Electron Microscope) images depicting monocline sulfur in Figure 12.

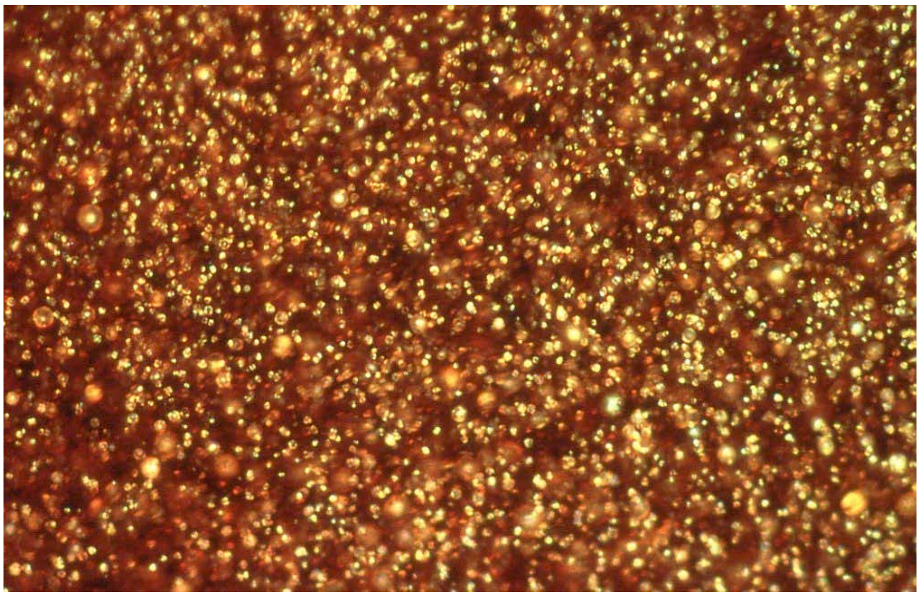

Figure 11: Globules of sulfur (2-3μ dia.) dispersed in asphalt

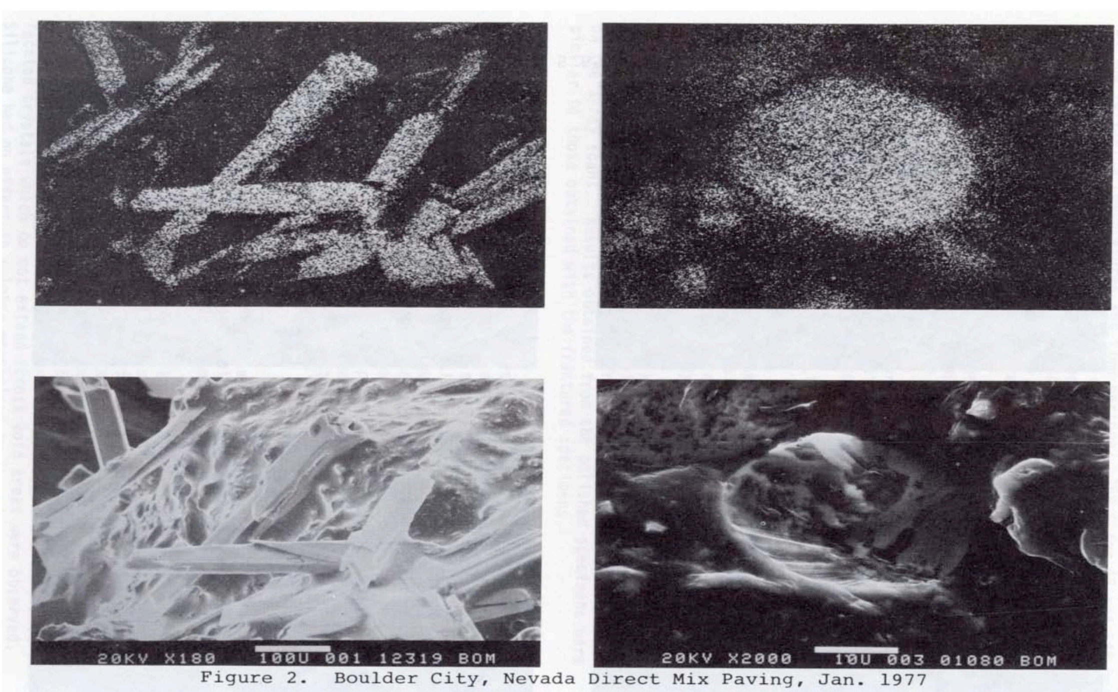

Figure 12: SEM images showing monocline sulfur crystals

This may have been the very first observation of an asphalt pavement material "Self-assembly". Since asphalt is classified officially as a nano-material, the observation may be also the first pavement self-assembly on 'nano-scale', which denoted a factor of 10^{-9}.

Before going into nano-technology, I must admit that choosing and using sulfur as a structural building block for pavements, like nature does for building most living organism, has a downside or 'sour' note. Sulfur abstracts hydrogen when surrounded by hydrocarbons, produces very small amounts of such odorous compounds as hydrogen sulfides, mercaptans or thiols. The odor emission levels at room temperature are found to be safe but still are a nuisance. Because of such ecological concerns the use of sulfur in asphalt pavements was largely discontinued. The upside to this research experience, are ideas and encouragement to explore nano-technology approach to design genuine sustainable pavements.

Nano-Materials:
A look at sea shells and other bio-mineralized marine fossils can be a good start to appreciate the auto–construction process or self–assembly evidence of nature (Fig.13).

Figure 13: Bio-mineralized marine fossils

The morphology as well as the interfaces between organic and inorganic materials are intriguing and may be of importance for asphalt and aggregate composition. Ozin and Arsenault point out in their recent 'Nanochemistry' textbook (19) the following five prominent principles, which must be considered when working with materials self-assembly of a targeted structure from spontaneous organization of building blocks beyond the sub-nanometer scale: (1) building blocks, scale, shape, surface structure, (2) attractive and repulsive interactions, (3) reversible association-dissociation and adaptable motion of building blocks in assembly, lowest energy structure, (4) building block interactions with solvents, interfaces templates, (5) building dynamics, mass transport and agitation.

The research of nano-materials for transportation infrastructure, i.e. a novel approach to materials development, started recently at the beginning of the 21st century. Meanwhile other engineering applications, such as nano-electronics, nano-instrumentation, nano-biotechnology, etc., have been progressing for over a decade. The "Lotus Effect' is an interesting example to illustrate a nano-engineered rough surface which can keep itself cleaner than a smooth surface (Fig.14).

A water drop on a smooth surface pushes dirt particles around before rolling off. A nano-scale rough surface with a coating of super hydrophobic waxy crystals, modeled on the leaf of the lotus flower at the Bonn University, Germany, encourages pick-up and retention of contaminants by the water drop before it rolls off the surface (20). The possibility of an autonomic sealing and healing of micro-cracks in asphalt pavements has been described by researchers at the University of Illinois, Urbana-Champaign (21). The healing reaction is triggered by incorporating a microencapsulated catalytic chemical within an epoxy matrix. When hairline cracks are starting to form in the pavement, the embedded microcapsules release the catalytic agent into the crack plane and the polymerization and bonding of the crack faces is initiated.

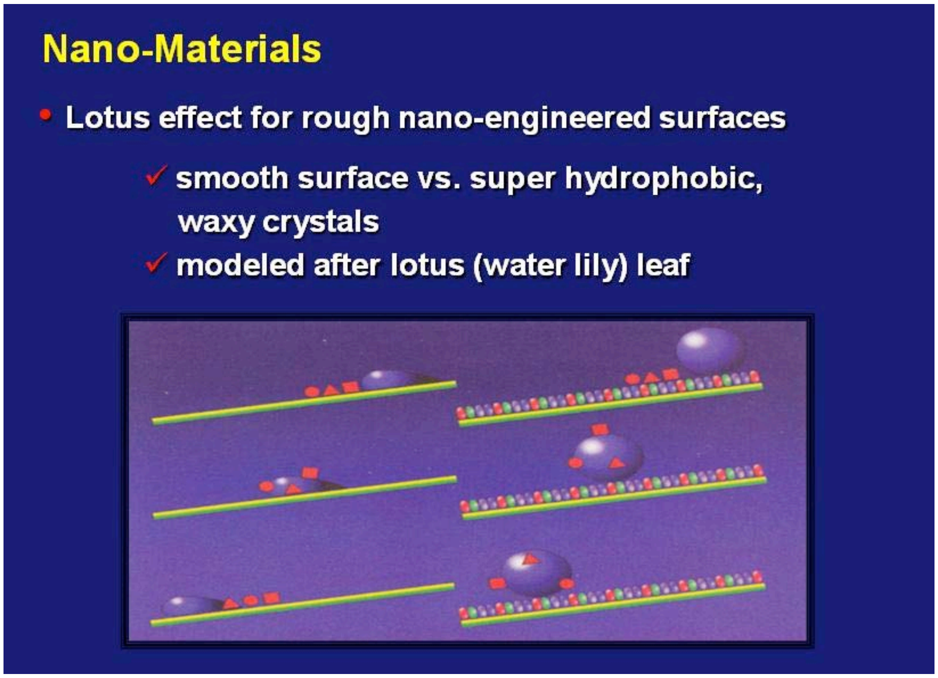

Figure 14: Lotus effect for nano-engineered surfaces

5.0 Conclusions and Recommendations

The keynote lecture is essentially a retrospective of the asphalt pavements' performance in view of environmental criteria and expectations as these evolved over the history of road building and transportation. The main thrust, including the identification of issues and challenges need to address these issues, basic concepts, approach and timing for dealing with the challenges and potential opportunities. The main transcending conclusions and recommendations are summarized here:

5.1 Conclusions

1. The asphalts' pavement success is largely based on such key features as the oldest building material known to mankind, 4000 years of diverse environmental applications, performance targeted production (low Vapor pressure), proven recycling technology, and most cost-effective paving material in existence.
2. The importance and scope of environmental concerns and challenges have increased dramatically towards the end of the 20th century and the approach and the steps to cope have to be adjusted accordingly.
3. The expanded version of environmental protection must now recognize the existence and concepts of ecosystems as well as their functions and inter-relationships.
4. Any negative impacts due to uncontrolled economic development must be accounted for and balanced in order to achieve sustainable development.
5. In order to address the challenges and environmental problems effectively, the approach and criteria should be based on fundamental science concepts and sound engineering principles. Whenever fundamental principles are not defined, it is prudent to follow nature. "Look deep into nature, and then you will understand everything better" (Albert Einstein).
6. In order to understand and assess the environmental impact of asphalt pavements, one must address in addition to environmental protection also ecology and sustainability as well as standards, policy and the environmental law.

5.2 Recommendation.

1. Based on the observation that the industry not only faces an evolving wider scope of the environment but also new standards, policies, and environmental laws, it is recommended that to maintain in these matters the status of responsible disposition, the industry should try to stay abreast of technology and policy development as a group. Awareness, educational and research programs are also suggested as demonstrated by staging this symposium.
2. When we are addressing the future direction and opportunities of our industry, the recommendation is "research'. We are dealing here with shared benefits. Managing common–pool natural resources is destined to be a joint venture and requires a concerted effort.
3. A refocusing exercise on the new direction and adjustment of our vision for the future is recommended as a first step (see section 4.2).

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