RESEARCH AGENDA FOR SUSTAINABLE PAVEMENTS

AN INTERNATIONAL ROADMAP FOR RESEARCH AND COLLABORATION

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Pictures courtesy of Ulf Sandberg

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INTRODUCTION

The provision and maintenance of a reliable and sustainable infrastructure is a priority for all countries. Societal stability, sustainable growth, quality of life, and resilient response to natural and man-made disasters all rely extensively on efficient, well-maintained infrastructure networks (roads, water pipelines, electrical grids, etc.). In particular, the road infrastructure is of central importance and a critical lifeline in developed societies – carrying 89% of all passenger miles and 41% of all ton-miles for land freight transport in the US. The picture for passengers is similar in the EU, where roads carry 83% of all passenger miles, whereas roads carry 81% of the EU's land freight transport[1]. At the same time, the pavement structures consume a large percentage of the resources allocated for the provision, and management of the road infrastructure. Because of its importance, its ubiquity and past and ongoing investment, highway construction is one of the most important areas of infrastructure where sustainability must be achieved.

Having identified this need, the Center for Sustainable Transportation Infrastructure (CSTI) of the Virginia Tech Transportation Institute (VTTI) and the Nottingham Transportation Engineering Center (NTEC, part of the University of Nottingham in the UK) led the development of this "Agenda". Both Centers are very experienced pavement engineering research groups with strong sustainability foci. Having secured the sponsorship of the National Science Foundation (NSF) and the Federal Highways Administration (FHWA), they aimed to develop a roadmap for research that would be capable of making a major contribution to securing pavement materials, systems and networks that are far more sustainable than at present.

A broadly stated sustainability framework for research, which includes a full understanding of sustainable pavement assets, has the possibility of delivering real advances. For this reason, the work deliberately took a wider view than the issues of carbon generation and carbon reduction. Some advances that will assist in delivering more sustainable pavements are within the research community's grasp. Others will require concerted, collaborative and highly innovative approaches that will almost certainly take longer to deliver benefits. Most sustainability issues are international in scope while specific advances in sustainability thinking, measurement, expertise and practice are often localized to one nation or region. For this reason this Agenda is intended to be of multi-national use and to encourage the use of the key developments concerning sustainable pavements, wherever they may be located. To achieve this, collaboration is seen as a key aspect.

MISSION

The mission of this research agenda is to increase the sustainability of our pavement materials, systems, and networks through focused research, innovation, education, and technology transfer.

[1] EU 2007 & US 2006 data from "EU Energy & Transport in figures", European Communities, 2009

VISION

The vision of the many contributors to this Agenda was to create a Roadmap that:

- Offers a strategic approach for increasing the sustainability of our pavement materials, systems and networks,
- Identifies the main pavement-related research challenges,
- Provides an organized program of research efforts, strategic collaborations, and education and outreach activities to facilitate the provision of a more sustainable road infrastructure, and
- Becomes the reference of choice for agencies and organizations developing programs for increasing the sustainability of pavement materials, systems, networks, and asset management programs.

GOALS

The main goals of this Agenda are:

- To identify the main issues associated with the design, construction, and management of sustainable pavement systems
- To define the future research efforts that are needed ,and
- To establish a 'roadmap' for the delivery of the needed research.

METHODOLOGY

The genesis of this agenda was an international workshop that brought together the leading researchers in this field from the US and Europe to compare and contrast best practices around the globe, to explore the vital subject of sustainable pavements, and to develop a roadmap for future research needs. The workshop was held at the Airlie Center in Virginia, USA on January 7-9, 2010 under the sponsorship of the National Science Foundation and the Federal Highway Administration (FHWA). The program included plenary sessions, led discussions, breakout groups and an open forum.

The three plenary sessions focused on "big picture' issues, pavement materials, and pavement systems. Each session was led by a 'champion' who was appointed to oversee the session and to draw out the key issues, hindrances to progress, directions, and opportunities. A scribe was also appointed for each theme and charged with summarizing and reporting the discussions from the plenary and break-out sections. The intent of these technical sessions was to share best practices and research expertise among attendees from Europe and the US. The topics addressed in these sections, and the presenters, are summarized in Appendix 1.

Three parallel breakout sessions were arranged around the three themes of the preceding plenary sessions. The sessions were designed:

- to identify the restraints to the provision of sustainable pavements, in particular those that appear amenable to change in the short, medium and long-term,

- to identify the technical and societal challenges that must be addressed to deliver such change, and
- to identify "quick-win" and longer-term strategic research goals and study areas that are necessary precursors of the desired step-change in pavement sustainability.

The workshop concluded with a final session that provided an opportunity for all participants to review the results from the break-out sessions. It also allowed for further discussion of the identified gaps, challenges, and research needs, and the development of a work plan.

The workshop setting was chosen to offer an environment for an open exchange of experiences and practices, promoting creativity by generating a wide variety of research needs and ideas. During the workshop, the participants:

- reported on the most recent research advances and current developments in pavement materials engineering and pavement construction that deliver environmental and sustainability benefits,
- investigated means by which the level of sustainability of pavements and their constituent materials can be evaluated, and
- determined the relative areas of strength and expertise in Europe and North America with a view to fostering international research collaboration that will benefit both regions.

The document produced at the workshop was further developed and organized to prepare a draft Agenda that was sent to all participants and discussed at a series of webinars.

The main conclusion of the workshop was:

> *For pavements, business as usual is NOT sustainable. However, focused near-term research will provide practical, scientifically-based tools and solutions to effectively guide decision makers. Strategic research in areas identified in this document will provide the scientific answers necessary to support the green economy of the future.*

CHALLENGES

The identified challenges to a more sustainable pavement infrastructure can be grouped as follows:

A. Resources currently relied upon in the transportation paving industry are becoming more scarce and costly.

- Petroleum-derived bitumen is currently almost the only binder used in asphalt pavements.
- Portland cement has a high carbon footprint.
- Algae, corn, or other vegetation could potentially be used to develop renewable plant-derived binders but must compete for land-use.
- Alternative hydraulic binders, often industrial byproducts, have low embodied carbon but can sometimes have adverse environmental impacts.

- Virgin aggregates are more costly and more difficult to obtain due to both availability and environmental concerns.
- Greater usage of locally available resources is made more difficult by the limited number of materials currently considered acceptable for use. The performance of marginal materials is poorly understood. This is also true for the re-use of materials from non-pavement origins in pavements.
- Repeated reuse of paving materials is not currently widely (or systematically) practiced.
- Fuel used to power equipment and produce materials is becoming more expensive and the resulting emissions are becoming of great concern.
- Water and energy needed for material production and on-site activities, faces an increase need for conservation.
- Space for disposing removed pavement materials is becoming scarce and less accepted by the public, which is also afraid of long term pollution of soil, ground water, etc.

B. **Public expectations are rising even as resources decrease and constraints increase.**

- The general public has higher expectations for acceptable ride quality, safety, noise levels and delay/congestion, while higher traffic loads and frequencies demand increased bearing capacity, which typically translate into the use of more resources.
- At the same time the public wants to see a more sustainable delivery of these expectations. Therefore, in the same way as the public looks for measures of ride quality, safety, etc., it can be confidently predicted that the public, and public bodies, will also expect indices and prediction methods, which give some measure and assessment of sustainability.
- The challenge is to provide rating indices that meaningfully relate to the materials and methods employed in making and maintaining pavements. These can be used to guide public perception in a direction that is in harmony with a scientific understanding of the problems associated with delivering a sustainable pavement network. The greatest challenge in this area is to deliver indices, so convincing and credible, that it would allow the public's service level demands to be moderated in the light of their non-sustainability.

C. **There are many problems in measuring the sustainability of pavements in a scientifically robust and publically acceptable manner.**

- There is little global agreement on the best manner to measure sustainability in a holistic way. This severely limits our ability to predict, monitor and evaluate improvements in sustainability.
- Metrics, which should be common and broadly accepted, would allow the setting of benchmarks, which can then be used to encourage continuous improvement in comparison to initial levels of sustainability, assessed using such measures. It is a

major challenge to derive metrics that are acceptable, scientific, usable and transferrable across all pavements.

- Obtaining reliable data for use in metrics and indicators will not be a simple task.
- Understanding and expertise in considering and assessing sustainability concerns is lacking. Limitations in current skills and knowledge base will likely hinder the adoption of new indicators and tools. Certainly one can expect resistance to learning the new skills that will be necessary to make progress in measurement and assessment.
- Decision makers at all levels need tools to assess sustainability and support decision making. Prioritizing, trade-offs, and threshold values will be important considerations with the potential uses of these tools.
- There is a lack of communication and understanding between engineers, decision-makers, the media, politicians, users and other stakeholders. Beyond the tools needed to support engineering decisions at the project, network and strategic levels, there is a need for easy-to-understand indices or eco-indicator numbers for effective communication with non-engineering users of information regarding the interaction of pavements and the environment.

D. It is difficult to implement more sustainable options due to institutional barriers and related factors.

- Current practices and financial restraints often discourage change and innovation in favor of established technologies, materials, and techniques.
- At times, decisions are focused more on short-term pressures than sustainable long-term effects.
- Many areas have laws requiring prioritization of low-bid procurement in project level decision making and do not allow sustainability to be considered alongside price. This does not encourage innovation.
- Quality assurance and regulative systems are usually restrictive and tend to work in opposition to sustainable approaches aimed at maximizing use of available resources and minimizing environmental impact (including energy consumption).
- Industries that benefit from existing systems, and that are concerned that they may suffer from change, will resist implementation of new requirements or certification procedures.
- Funds will have to be generated to support the development of more sustainable technologies and techniques, in an industry that typically relies heavily on public investment.
- There are no easily available resources to fund education and expertise-building programs to build up and sustain knowledge, databases and long-term evaluation programs.

E. Change is the only certainty for the transportation industry in the long term.

- Technologies, materials, vehicles, national and international demographics, lifestyles, economies, user need requirements, policies, regulations, climate change and other factors influencing the transportation industry are all highly variable.

- Developments in sustainable transportation engineering are fragmented, both by geography and discipline, yet high-quality solutions and novel ways of thinking are emerging.
- Decision makers, the media and the public are likely to find the changes required difficult to understand and difficult to manage.

RESEARCH NEEDS

To address the challenges listed in the previous section, the workshop participants identified the following research needs.

1. Sustainability Assessment Methods

Methods of assessment are needed to assist with decision making and measure performance. A staged approach is needed, starting with identifying what to measure and how to measure it, to provide a relatively simple assessment system in the short-term, albeit limited in scope. This should then be extended into a broader decision support tool, after adequate validation. Furthermore, these sustainability assessment methodologies should be guided by, and feedback to, high-level goals that reflect national or international policies and desires.

1.1 Indicators

A set of metrics needs to be developed that will allow owners and the public to define a 'sustainable pavement'. These metrics need to cover corporate responsibility, materials, paving systems, construction methods, maintenance treatments, resource consumption, environmental impact (health of residents and users, waste management, carbon emissions generation) and asset management decisions.

Indicators should be selected in a robust and open manner, which includes international stakeholder consultation, economic, social and environmental metrics, and consideration of acceptable target levels and actions for achieving them. This may require the involvement of team members from outside the traditional pavement engineering field.

The metrics must be scientifically founded, unbiased, quantitative when possible, and subject to peer review. The "measurement" process must include agreed-upon and reasonable system boundaries, which places paving within the wider transportation system.

Data should be specific enough to be accurate and relevant, yet on a wide enough range of materials, equipments, procedures, etc. to be representative. It must be up-to-date and appropriate for the geographic location and social environment in which it is being used. Variability must be understood.

1.2 Sustainability Rating System

During the early stages of indicator development, a methodology should be developed to provide an assessment of pavement sustainability, on a qualitative and quantitative relative scale, to assist in decision making in the short-term but considering both short and long-term views. This should be based upon a life-cycle approach and include considerations on the impact of pavement decisions on the wider transportation system. This rating systems should include but not be limited to a life-cycle carbon footprint tool (e.g., compliant with the terms of the ISO Life-Cycle Analysis (LCA) standards).

Initial metrics should be limited to those which can already be measured with confidence. Other impacts should be managed by adopting a precautionary approach. As modeling, validation and peer review mature, a broader set of indicators can be developed and integrated into the assessment system.

Sensitivity analysis should be used to assess the robustness of the rating system. Measures of sustainability that can be understood by the general public are required before meaningful and useful metrics can be adopted.

A database of indicator values should be established to act as a benchmarking tool. Hot-spot analysis will identify the operations with largest environmental impacts and be used to support decisions about product and system development.

By assessing case studies and design schemes, the tool will be used to recommend best practice for sustainable pavement management. As the research progresses, these recommendations will grow, with the aim of creating a comprehensive assessment system.

1.3 Sustainability Decision Support Tools

A Multi-Criteria Decision Assessment (MCDA) tool must be developed for project and network level decision making. The tool should allow the balancing of risk, while rewarding and encouraging the development of more sustainable materials and practices (see 2.1). This more comprehensive tool will eventually replace or modify the rating system. This should be based upon a full environmental Life-Cycle Analysis (LCA), combined with further indicators chosen to reflect the interests of a full range of stakeholders in a tool that is transferable across a range of scenarios and responsive to wider transport decisions. The tool should be flexible, for analysis of short, medium, and long-term environmental, economic, and social assessments and should allow that 'lifecycle' can have different meanings in different contexts.

The tool should take into account and build upon already existing decision-making practices, without constraining innovation. It will be used to refine the definition of best practice by adding commentary on thresholds for indicator values, reflecting environmental limits or social acceptability. Benchmarking, target setting, auditing and certification should be explored.

1.4 Vulnerability to Climate Change

Product development, see 2.2 below, will respond to the need to reduce greenhouse gas and other emissions. A system-based life-cycle carbon footprint tool, as part of the wider assessment tool described above, can be used to measure the progress of the pavement industry in attempting to reduce emissions and mitigate climate change.

Pavements must also be able to withstand the extreme weather events predicted to arise as a result of climate change. A review system will be required to asses this vulnerability, as a first stage to recommending redesign or improved specification.

2. Innovation

Incentives are needed to develop and introduce innovation. Innovation may have high initial cost or risks but is a prerequisite to the improvement of sustainability in the longer term.

2.1 Financing and Risk

There is a need to develop and promote methods of procurement that encourage the development of more sustainable materials and practices, by achieving a balance between risk and reward. This may require the use of a rating tool (see 1.2 and 1.3) to assess the potential benefits of innovation as part of a new business model including clients and suppliers. New approval mechanisms for innovative products and practices should be considered, including the possible dedication of a proportion of research funding to high-risk, high-reward research, and to institutional strengthening. International partnerships should be developed and maintained.

2.2 New Products

More sustainable pavements must be based on more sustainable materials and processes. Although many issues concerning materials have been considered, the key advances are likely to include alternative low-carbon binders, efficient recycling/reuse of materials, and improved understanding of micro-and macro-deterioration mechanisms. Paving materials also have the potential to act in a multifunctional way such as drainage systems, to absorb air pollution, to generate energy and to reduce urban heat island effects.

2.3 Novel Pavement Systems

Pavements can provide benefits within the wider pavement/tire/vehicle interaction system. This will require a multi-functionality that addresses a wide range of impacts including but not limited to, rolling resistance, noise, skidding resistance and safety, durability and environmental impact. Different uses and locations may require a different balance between these properties, which may be assessed by a sustainability assessment tool (see 1.2).

Wider considerations include construction methods, maintainability, health and safety, speed and quality. Furthermore, additional uses beyond the basic transportation functions should be considered (e.g. pavements might be useful sources of solar energy generation and might be used to control water runoff).

2.4 Optimized Pavement Management Programs

To ensure the most sustainable solutions are implemented will require more than merely employing optimal materials and systems. Additionally, sustainable pavement management approaches need to be developed, tested and implemented. For example, there is need to consider intervention levels and treatments that will contribute more effectively to achieve sustainability goals.

2.5 Uncertainty

Product development should also pay attention to potential requirements for future adaptability. This may include climate change impacts and regulation, the low-carbon economy and water and air quality regulation. This adaptation refers to materials and paving systems and also to road vehicles and traffic management. A wider review of future potential requirements and regulation is needed, while acknowledging that the future may defy our predictions.

2.6 Standard Testing/Certification Practices/Protocols

An important stage of product development is laboratory trials and experimental pavement sections with further work being required to improve laboratory tests to better reflect in-service performance and sustainability impacts. Established protocols that include sustainability measures are needed to homogenize product testing, acceptance, and/or certification.

For example, there is a lack of properly developed criteria for qualifying marginal and recycled materials for wider use as pavement materials. Additional testing during and after construction, may be required but is not yet defined from a sustainability perspective. Evaluation and certification procedures will be needed for innovative materials and techniques (examples include photocatalytic materials and prefabricated pavements). Such certification should include long-term monitoring and validation that is backed by an appropriate LCA.

3. Guidance

Dissemination of the sustainable pavement concept, of new approaches and of measurements, indicators and assessment tools will be vitally important in order to achieve a step-change in the provision and operation of sustainable pavements.

3.1 Best Practice

Best practice should be identified and disseminated to a wide audience including researchers, industry and clients. Retraining programs and educational resources will need to be developed to include best practices.

3.2 Integration of Sustainability into Procedures/ Specifications

Integrating sustainability into the decision making-processes and contractual specifications is needed to ensure that more sustainable practices are actually implemented. This integration will be clearly linked with the communication plan discussed later in the document.

3.3 Consideration of Future Trends

The guidance, standards, and procedures developed to foster more sustainable pavement materials, systems, and programs should be adaptable to accommodate changes that the transportation industry is certain to face in the long term (see 2.5). A long-term research effort should develop mechanisms to effectively forecast the most significant changes and pro-actively adapt to these changes.

RESEARCH PLAN AND TIMELINE

The following table summarizes the main research studies that have been identified as necessary to address the challenges listed in Section 2, and organizes them based on the estimated time for the outcomes to be ready for implementation. For example, the category "Short-Term" would produce outcomes that may be ready for implementation in 1 to 3 years.

Theme	Short-Term (1-3 yrs)	Mid-Term (4-6 yrs)	Long-term (>7yrs)
1. Sustainability Assessment	1.1. Define Sustainability indicators relevant to pavements 1.2. Define pavement life-cycle assessment framework	1.3. Develop simple but scientifically-based quick-guide sustainability index 1.4. Develop national /international database of products and processes 1.5. Respond to high-level goals and check that goals are reasonable 1.6. Develop multi-criteria decision support tool(s)	1.7. Calibration, validation, and actualization of sustainability multi-criteria decision support tool(s) 1.8. Model to measure the effects of pavements on the overall industrial ecology
2. Innovation	2.1. Identify potential novel approaches for trying new materials/ systems 2.2. Facilitate/ fund the development of more sustainable pavement materials/ systems/ management programs.	2.3. Develop standard testing/certification practices/protocols 2.4. Procedures to Identify & mitigate risks of using new materials 2.6. Establishment of a cooperative product evaluation/ certification body 2.7. Optimize the use of local and low-impact materials based on their performance. 2.5. Product/system development and optimization program, including alternative low-carbon binders, functionally-optimized surfaces, efficient recycling/ reuse of materials, and improved understanding of micro-and macro-deterioration mechanisms (Mid-Term to Long-term)	2.8. Monitor the long-term performance of the products/systems developed and feedback the results to the certification practices
3. Guidance	3.1. Develop list of best practices for sustainable pavement management 3.2. Synthesize what products could/need to be recycled 3.3. Training / outreach materials on sustainable pavements 3.4 Forecast future policy regulation and constraints on pavement industry	3.5. Identify and adjust specifications and codes that need to be changed. 3.7. Launch assessment tool(s) and provide training/ support (Mid-Term to Long-term) 3.6. Demonstration/ assessment projects for "sustainable" pavement ,materials, systems an programs (Mid-Term to Long-term)	

Many of these research problems will require multi-disciplinary teams with members drawn from outside the traditional pavement research field. Effective working across disciplines cannot be achieved immediately, as it will take some time to develop effective communication between researchers from the different disciplines. This will, likely, require that new funding mechanisms are established to ensure the full benefits of long-term collaboration are obtained.

COMMUNICATIONS PLAN

There is a need to undertake awareness programs to promote the importance of, and progress towards, sustainability of pavements for policy makers and for the public. Collaboration among the various stakeholders, industry, government, academia, and the general public, will be needed to engage policy-makers and facilitate change. Expertise outside the realm of engineering is needed to effectively communicate to the public and to policy makers. A communication plan is needed, potentially involving expertise in public relations and public policy.

CONCLUSIONS

The demand for a step change in sustainable pavements is becoming ever stronger. Much information and many skills are available but they must now be integrated and exploited to deliver tangible and lasting advances. The workshop held in January 2010 successfully brought together key researchers to drive our response forward. This Agenda is the result. It has sought to identify, elaborate and order a roadmap for research in this important subject area – a roadmap that will have broad acceptance in the pavement research and pavement owner communities.

As the key output of the workshop, this document sets out the optimal strategy for making a step-change in the sustainability of our pavement assets. It lays out:

- A definition of the main challenges that require research if pavements are to form a more sustainable part of the transportation infrastructure,
- A strategic approach for increasing the sustainability of our pavement materials, systems and networks,
- The research needs that will give short- and longer-term advances,
- A plan and timeline of research efforts to facilitate the provision of a more sustainable road infrastructure, and
- An associated communication plan.

The appreciation of the importance of sustainability, and of the enormity of the challenges that it brings, continues to develop rapidly. Therefore, the contributors to this Agenda expect that it will need to be a dynamic document to reflect this. It is their intention that this Agenda becomes the reference of choice for agencies and organizations developing programs for increasing the sustainability of pavement materials, systems, networks, and asset management programs.

APPENDIX 1 - LIST OF PARTICIPANTS AND SPECIFIC TOPIC OF CONTRIBUTION

1. Tomas Harman (FHWA)	Sustainable ("green") roadways
2. Kamil Kaloush (Arizona State University)	Climate change impact on pavement engineering
3. Kevin Gardner (University of New Hampshire)	Measures of pavement sustainability
4. Crysta Highfield (Virginia Tech)	Life cycle assessment of pavements materials
5. Howard Marks (National Asphalt Pavement Ass.)	Carbon footprinting
6. Gerardo Flintsch(1) (Virginia Tech)	Sustainable asset management
7. Trenton Clark (Virginia DOT)	In-place cold recycling
8. Hussain Bahia (University of Wisconsin)	Use of high recycled content
9. Choubane, Bouzid (Florida DOT)	Concrete recycling
10. John Harvey(1) (University of California, Davis)	Warm-asphalt technologies
11. Williams, Christopher (Iowa State University)	Alternative binders
12. Magdy Abdelrahman (North Dakota State Univ.)	Rubber recycling
13. Larry Scofield (American Concrete Association)	"Quiet" pavements
14. David Lee (University of Iowa)	Innovative pavement systems
15. Kevin McGhee(2) (Virginia DOT)	Special surfaces
16. Edgar de León (Virginia Tech)	High-friction Surfaces
17. Paulo Pereira (U Minho, Portugal)	Novel measures of pavement sustainability
18. Tony Parry(2) (U. Nottingham, UK)	Life cycle assessment of pavement systems
19. Maurizio Crispino (Politechnico di Milano, Italy)	Photocatalytic pavement technologies
20. Pauli Kolisoja (U Tampere, Finland)	Soil treatment with non-traditional stabilizers
21. Andrew Dawson(2) (U. Nottingham, UK)	Use of secondary and recycled products
22. Ulf Sandberg (VTI, Sweden)	"Quiet" pavements
23. Brian Ferne (TRL, UK)	Perpetual pavements
24. Martin van de Ven(1) (TU Delft, Netherlands)	Innovative pre-fabricated pavement systems
25. Manfred Partl (EMPA, Switzerland)	Optimized thin surfaces

(1) Champion (2) Scribe