

Eco-Road Building for Emerging Economies: An Initial Scan for Promising Alternative Technologies

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Foreword

This report has been initiated and funded by the global Transport Knowledge Partnership (gTKP) for the benefit of developing and transition countries.

The gTKP is a platform for making effective use of the best available transport knowledge and facilitating strong participation from developing and transition countries. gTKP is driven by the needs of its users and has a strong focus on the participation of transport practitioners around the world. Through its work, gTKP arms practitioners with knowledge and builds partnerships to improve decision making and help to alleviate poverty.

gTKP's focus is on long-term capacity building to deliver an effective approach to tackling world transport issues. Its overall goal is to contribute to the achievement of the Millennium Development Goals through transport knowledge.

For further details, visit the website on: www.gtkp.com

This report is aimed at persons or organizations interested in developing renewable locally sourced alternatives to conventional bitumen, asphalt and Portland cement based materials for low cost road building. The report demonstrates the potential for the development and application of more sustainable and environmentally sound technologies with the benefits of local small scale production, low capital requirements, local productive employment creation suitable for men and women, reduced road maintenance, reduced materials transportation and mining/quarrying. Potentially this would be a substantial initiative facilitating social and economic development, and poverty reduction.

The views expressed are not necessarily those of gTKP, the DFID or any other of the supporting organisations.

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Abbreviations, Acronyms & Technical Terminology

Gravel - Naturally occurring material which can be excavated and used successfully in certain conditions as a low traffic volume road surface if complying with certain grading (aggregate sizes) and plasticity requirements, and watered and compacted.

Bitmac - Short for bitumen macadam; a dense compacted mix of bitumen (asphalt) and aggregates to form a road pavement layer of low or very low porosity.

Cellulose - An organic polysaccharide consisting of the elements carbon, hydrogen and oxygen organised in linear chains of glucose units ranging from several hundred to many thousands of units long. Cellulose is the structural component of plant cell walls and is the most common organic compound on Earth. For pulp and paper manufacture, cellulose is obtained largely from wood (50% cellulose), but many agricultural by products such as cereal straw are also used.

Iodine No. - The mass of iodine in grams that is consumed by 100 grams of a chemical substance. The iodine number is a measure of the number of unsaturated carbon bonds (double bonds) contained in fatty acids, as these react with iodine. The higher the iodine number, the more unsaturated fatty acid bonds are present in a fat, and the more susceptible the fat is to oxidation and polymerisation.

Kraft Paper - Is produced by the kraft or sulphate process which removes the lignin from wood chips by heating with sodium hydroxide and sodium sulphide to yield a pulp which is almost pure cellulose. The paper made from it is strong but initially brown in colour. Kraft paper can be bleached to produce a high quality white paper which does not yellow with age.

Lignin - Lignin is a very complex and variable polycyclic organic chemical compound, which plays an important role on the structure of plant cell walls, acting as the “glue” holding cellulose fibres and other polysaccharides together. Lignin has to be solubilised and separated from cellulose in order to make paper and is therefore a waste stream from paper pulp mills, e.g. the Kraft process.

Lignocellulose - Comprising cellulose molecules bound together with lignin, this natural composite gives plant cell walls and hence fibres their strength. Typical lignocellulosic fibres are Sisal and Coir.

OPC - Ordinary Portland Cement

Polymer - A chain of identical molecules (monomers) chemically bonded together to form a material having significantly different properties from the original monomer. For example ethylene, a gas, becomes a highly flexible water resistant plastic, polyethylene when polymerised.

Tarmac - Short for tar macadam; a dense compacted mix of tar and aggregates to form a road pavement layer of low or very low porosity. Commonly used to describe bitmac despite the tar binder having fallen into disuse in most countries.

Executive Summary

There is a major requirement for various sealers and binders in the global road infrastructure sector. The principal need is for the construction and maintenance of road surfaces/pavements. There are obvious substantial environmental disadvantages from the production of the currently used binders-sealers which are mainly fossil fuel (bitumen/asphalt) or cement based. These involve energy intensive production and long transport distances from large scale production facilities to the point of application. For developing countries these products are usually imported and must often be transported long distances and over roads susceptible to damage from heavy vehicle loading. As fossil fuel prices rise, these products are an increasing strain on scarce foreign exchange resources.

It is believed that a significant proportion of these imported raw materials could be substituted with locally sourced alternatives. These could arise from local agricultural and manufacturing operations, and waste streams from industrial activities and power generation. It may also be possible to provide demand for new agricultural crops (without compromising current food crop production) and hence encourage new manufacturing opportunities using appropriate technology to deliver suitable road building materials. Such innovation could stimulate local economies as well as reduce the carbon footprint of road building activities.

This report is the result of a technology scouting exercise (see “Methodology section” below) The output itself is a series of abstracts from promising leads or stories copied from the search findings, which range from academic papers, theses etc. through news reports to company promotional literature and patents.

Six main technology areas with significant potential for beneficial exploitation for road surfacing and paving purposes have been identified and are recommended for further examination in follow up workshops:

Wood or Palm Lignin

Lignin is one of the most abundant organic polymers in the world, containing 30% of non-fossil organic carbon, about 50 million tons is produced annually as residue in paper production. In the form of Lignin sulphonate, a paper pulp industry waste stream, it has been used for about a 100 years to control dust and stabilise gravel on unpaved roads in the USA and Sweden. Furthermore, the new biofuels industry is expected to deliver abundant fibrous lignin from palm oil extraction. There is very considerable potential for innovation based on recent advances in wood biochemistry. Opportunities include:

- Understanding how lignin fibres could be modified/optimised for use in pavement stabilisation
- Combination with other materials such as drying oils, tall oil or black liquor (a resinous paper industry waste stream) to improve water resistance of unsealed road surfaces
- Low cost manufacture or conversion of crude lignin waste streams direct from the paper mill or oil pressing plant for road use.

Pine Resin or Tall Oil

Tall oil, also called liquid rosin or tallol, is a viscous yellow-black odorous liquid obtained as a by product of the Kraft process of wood pulp manufacture. Tall oil is a mixture of fatty acids and resins which tend to be separated into “Tall oil rosin”, “Tall oil pitch” and Tall oil fatty acids, and have been employed as a tar/bitumen substitute often in combination with other bio materials.

Drying oils and Semi drying oils

A “drying oil” is an oil which hardens to a tough, solid film after a period of exposure to air. The oil hardens through a chemical polymerization reaction in which oxygen is absorbed from the environment. This property is the basis of conventional paint technology. The cross linking process can be manipulated by catalysis heat and oxygen. Unsaturated vegetable oils are widely available from a range of oil seed crops and, through the new biofuel industry, non food vegetable oils such as *Jatropha* are becoming available. In combination with other locally available biopolymers it should be possible to devise waterproof sealing systems with sufficient resilience for low volume road surfacing.

Oil, Resin and Biomaterial blends

After a long history of patented mixtures and often inadequate performance in low maintenance surfacing, recent innovations using blends and emulsions of pine pitch, rosin and vegetable oils have begun to reach commercial success as ecologically acceptable alternatives to bitumen based products. More sophisticated control over polymerisation conditions using oxidation catalysts and various pre-treatments may have lead to this success. Examples are “Vegecol” colourable pavement system from Colas, and Ecopave from Australia which appears to use a wide range of organic waste streams and may be adaptable to a variety of local resources. This is probably the most promising approach for replacement of bitumen/asphalt binders as both technology and experience in use is available. The challenges will be cost and appropriate technology implementation.

Pozzolanas as Cement Substitutes and other waste streams

One of the most exciting opportunities is the replacement of Portland cement with rice husk pozzolanas and lime. Up to 130 million tonnes of husk could be available annually on a global basis for pozzolana production. As the ash content by weight is about 20%, there are potentially 26 million tonnes of Rice Husk Ash (RHA) available as a pozzolana. Other sources of Pozzolanas include fly ash from power stations, kilns and furnaces. Apart from the attractions of cost and foreign exchange savings and zero net carbon footprint, there is scope for encouraging local low technology industries.

The challenges will be achieving high yields through combustion temperature control in simple combustion units.

Geotextile and Biofibre Reinforcement

This opportunity would access the approximately 2×10^{11} tons of lignocellulosics produced every year world wide, making them one of the world’s most abundant natural raw materials. Numerous useful fibres are

produced as secondary or waste streams in tropical agriculture, from primary sisal, through coir fibre to maize stalks, rice straw and bagasse (from sugar cane). The opportunity is to incorporate such materials as textiles or random fibres for soil stabilisation and as fibre reinforcement for pavement structures, possibly in combination with biopolymers and pozzolanas.

The appendix contains further stimulus and leads which may facilitate a different or wider direction of thinking in the proposed workshops.

To sum up, there is enormous potential to escape from the high-energy, environmentally damaging, dependence on petrochemical and cement based industries, to develop sustainable, low carbon footprint solutions utilising local resources and initiate productive local employment in developing countries. This could create a fast-track solution to the universal provision of affordable, sustainable, basic access to the more than a billion people living in poverty in developing countries.

Eco-Road Building for Emerging Economies: An Initial Scan for Promising Alternative Technologies

Concept: The development of low-cost, sustainable road construction technologies using agricultural waste and by-products

1. Background



Photo-1:
Rural transport in South Asia

There is a major requirement for various sealers and binders in the global road infrastructure sector. The principal need is for the construction and maintenance of road surfaces/pavements. This function was formerly catered for primarily by the tar industry (particularly as the by-product of town gas production from coal). The demand is now primarily catered for by bitumen (asphalt) as a by-product of the petroleum refining process, and cement. There are obvious substantial environmental disadvantages from the production of both of the currently used binders-sealers; not least of which are the energy intensive production and the long transport distances from large scale production facilities to the point of application. For developing countries these products are often imported and also transported long distances over roads susceptible to damage from heavy vehicle loading. As fossil fuel prices rise, these products are an increasing strain on scarce foreign exchange resources.

The challenge for these countries is to develop their all-weather road networks in an affordable and sustainable way. Currently the vast majority of the rural roads are only to earth or (often) problematic gravel standard. This leads to isolation, unreliable access and high local transport costs. There is a pressing social and economic need to 'seal' or improve these roads, ensure all-season route passage and to facilitate development and poverty reduction initiatives without adversely affecting the environment.

Developing countries typically depend heavily on agricultural production as the means of both subsistence and economic activity. This activity relies predominantly on the transport sector for inputs and export of production. Unfortunately there is currently limited interaction between the agriculture and road sectors. There are some examples of agricultural products and wastes being beneficially used in the road sector. These include:

- The use of molasses from the sugar production process as a dry season road dust palliative (Tanzania),
- The use of paper pulp processing 'Black Liquor' as a gravel road surface dust palliative (Sweden),

- The firing of clay bricks using the waste rice husks for durable, low maintenance, road surface (Vietnam).

These applications are relatively isolated. However, there is an evident potential for developing 'organic' substitutes for bitumen or cement, to be used as a sealer or binder, from agricultural primary or waste products. There is also a possibility that these plant based/derived products could be created or processed on a small scale in rural locations to be used in that location with considerable benefits of reduced road materials transport, reduced environmental impact, local employment, local economic activity, social and infrastructure development, without compromising food crop production.



Photo-2:
Rural transport in Afghanistan

2. Disclaimer

The Appendix of this report contains text and images pasted from freely available information on the internet, and are therefore intended for private circulation within gTKP. The authors accept no liability whatsoever in respect of any accidental breach of copyright resulting from external publication of this material.

3. Methodology

This report was researched using a methodology called "Technology Scouting" which is a relatively recent innovation among information consultants, which has been successfully applied to projects within large multinational companies who wish to break out of their current technology and mindset constraints. Typically it would be used to find out if other industries or geographical regions are employing technologies which could be adopted in the client's innovation plans or if the new (to them) technologies suggest consumer innovations not previously contemplated.

In creativity terms the methodology draws on the concept of "Parallel Worlds" suggested by Michaelko ("Cracking Creativity" p198) and others. Two examples of the author's experience of output from Technology Scouting currently in client's development programmes are:

- Hydrophobic coatings from the aerospace industry applied to beverage cans
- Light emitting nanostructures from fabric research applied to personal care packaging.

Insights for this report were generated by applying lateral thinking to internet searches, and unstructured

skill based search strategies. The output is not intended to be an academic treatise but a list of ideas for development in one or more knowledge workshops recommended as a logical follow up, where technology experts and need experts generate ideas and implementation strategies for problem solutions in a creative atmosphere.

The output itself is a series of abstracts from promising leads or stories copied from the search findings, which ranges from academic papers, theses etc.. through news reports to company promotional literature and patents. Important leads are corroborated by follow up searches, but it must be emphasised that these items do not provide definitive answers but help us to decide where to look for future solutions to the problem of appropriate, low cost and low carbon technologies for rural road building in emerging economies.

4. Scope

What is in:

- The Report covers possible alternatives to conventional asphalts/bitumens (fossil fuel based binders and sealants) and cement based pavement construction and stabilisation
- The primary focus is on alternative renewable or locally available waste stream materials, mainly biological but with some promising non biological materials included
- Includes a preliminary scan of interesting patents
- Includes existing or commercial or near commercial applications
- Includes highly speculative new materials and possible chemical or biochemical innovations
- Includes a separate Appendix of raw documents from the internet trawl which may not be covered in the top line summary, so interested readers should scan it.

What is Out:

- The Report does not include an exhaustive review of the topic or patents
- Only a brief mention is made of alternative aggregates, but see the separate Appendix
- The report does not cover incremental developments of conventional technologies, but some historical methodologies are in the Appendix.

5. Hot Topics for Possible Inclusion in a Research Programme

5.1 Alternative sealants and adhesives

These are materials analogous to tar (un-diluted or diluted) and emulsified bitumen from fossil fuel or coal distillate sources, all of which usually have to be imported by the user in many developing countries incurring high raw material and transport costs. They have potential functionality as sealants and adhesives for pavement surfaces and as waterproof binders for tarmac/bitmac substitutes.

5.1.1 Wood or Palm Lignin



**Photo 3:
A pulp mill in Canada**

Lignin is the 'glue' that holds tree rings together. It is one of the most abundant organic polymers on Earth, exceeded only by cellulose, and containing 30% of non-fossil organic carbon. In the form of Lignin sulphonate, a paper pulp industry waste stream, it has been used for about a 100 years to control dust and stabilise gravel on unpaved roads in the USA and Sweden. For dust control, it can be sprayed onto an unsealed (gravel or earth) road surface. For stabilisation and dust control, it is better to mix it with the top few inches of road surface. It is water soluble, environmentally friendly, easy to handle and apply, and very cost-effective.

The benefits include increased load-bearing capacity (can be similar in strength to up to a 3-inch or 7cm layer of asphalt concrete), a firmer road surface without loose gravel, dust abatement, reduced frost-heave damage, and cost-savings in both construction and maintenance (Largely from Ref 32). Calcium lignin sulphate is a by-product of the Kraft paper process and is hydrophobic (not water soluble) whereas lignin sulphonate, which is a by-product of the sulphite process, is hydrophilic (water soluble). Pavements stabilised by lignin sulphonate alone would therefore have a short maintenance cycle (Ref 35). A key advantage of these materials is low cost and wide availability.

In the tropics lignin should be available as a waste stream from local paper industries using a variety of pulp feedstocks, including *Pinus patula*, *Eucalyptus*, crop straws and stems. It is also a by product of palm oil production and therefore will be available in increasing quantities as palm based biofuel industries emerge in the Far East.

Fibrous lignin is a by-product from the new biofuel industries and is currently receiving attention as a possible pavement binder. (Ref 31).

The application of wood biochemistry understanding from experts such as Michael Lindstrom and Gunnar Henriksson (Ref 17) to this application has potential to extend application range and performance, e.g. curing/blending properties for water resistance, and there may be significant scope for invention.

Further potential areas for research could include:

- Understanding how lignin fibres could be modified/optimised for use in pavement stabilisation
- combination with other materials such as drying oils, tall oil or black liquor (a resinous paper industry waste stream) to improve water resistance of unsealed road surfaces and hence increase the maintenance cycle
- Low cost manufacture or conversion of crude lignin waste streams direct from the paper mill or oil pressing plant for road use.

5.1.2 Pine Resin or Tall Oil

Tall oil, also called liquid rosin or tallol, is a viscous yellow-black odorous liquid obtained as a by product of the Kraft process of wood pulp manufacture. The name originated as an anglicisation of Swedish “tallolja” (“pine oil”). Tall oil is a mixture of mainly fatty acids and resins which tend to be separated into products such as “Tall oil rosin” “Tall oil pitch” and “Tall oil fatty acids” (Ref 36).

There is a long history of the use of tall oil usually in combination with pine pitch, or tall oil pitch, in the stabilisation of road pavements in the USA.

There is extensive patent literature on this technology, dating from 1943, which is reviewed in Ref 34.

Although there is some recent patent coverage, some of this may have lapsed by now and there is considerable prior art. The patents seem to avoid the obvious expedient of using unrefined Tall oil and blending it with additives to form a useful product.

There is clearly scope for development and invention here particularly in respect of the specific by-products available in client countries.

5.1.3 Drying oils and Semi drying oils

A “drying oil” is an oil which hardens to a tough, solid film after a period of exposure to air. The term “drying” is actually somewhat of a misnomer - the oil does not harden through the evaporation of water or other solvents, but through a chemical polymerisation reaction in which oxygen is absorbed from the environment (autoxidation) and the fatty acid chains link with each other to form an extremely large cross-linked polymer. Drying oils are a key component of oil paint and many varnishes. Some commonly used drying oils include linseed oil, tung oil, poppy seed oil, perilla oil and walnut oil. (Ref 37) The key property of drying oils is the proportion of double bonds in the carbon chain of the fatty acids, usually an iodine number (IN) in excess of 130.

Other oils are classed as semi-drying e.g. corn oil, cotton seed oil, soya oil, IN 115-130, and non drying oils e.g. olive oil, peanut oil, coconut oil, IN less than 115.

There is potential to use drying/semi drying oils for pavement sealing and as part of an adhesive mixture for wear surfaces.

The technical approach might be to blend the oil mixture with heavy metal salt catalysts, blow air through the mixture possibly combined with some heating to initiate polymerisation and decrease viscosity, and then spray onto the road surface, prior to rolling in a chip or gravel wearing surface. It is unlikely that an oil mixture alone would have suitable properties of adhesive strength and plasticity; see section 5.1.4 below for blend technology. Ideally, edible oils should not be used in road construction on grounds of cost and food competition.

There are a number of novel sources of low cost oils becoming available to tropical cultivation, e.g. *Jatropha*

(Ref 12) Pond algae (Ref 10), *Copaifera langsdorfii* (Ref 20), all of which would require validation of low cost production and suitability for pavement stabilisation or sealing applications. Some of these options would not involve conflict with land required for food production.



Photo 4: **Jatropha berries**



Photo 5: **Jatropha crop in Velchal India**

5.1.4 Oil, Resin and Biomaterial blends

Tall oil and resin blends have also been used for road surface dust suppression for more than a hundred years, as evidenced by the patent history dating from 1904 reviewed in Ref 34.

Various combinations of “lyes” containing calcium salts and alkalis in combination with lignin sulphonate, probably as crude waste streams from paper pulp manufacture blended with additives such as pine oil and pitch derived from tall oil. The problem with these mixtures is that they are not water resistant and either have to be re-applied or the roads and the surface re-shaped at a frequency related to weather and traffic loading.

More recent developments to generate stronger more waterproof pavements include specific mixtures and emulsions of pitch and rosin to form a “pine tar mixture” (Ref 33, Ref 34), addition of rubbers and plastics as auxiliary agents (Ref 28), and emulsions of vegetable oils together with crude tall oil (Ref 48). More recent inventions include other renewable additives such as drying oils and soap solution (Ref 30) and more recently (Ref 53, 2008) a system of natural and hydrogenated rosins together with drying oils, heavy metal salts as oxidation catalysts and various pre-treatments to initiate polymerisation.

The best reported commercial implementation of this technology is “Vegecol” colourable pavement system from Colas (Ref 29) which is being rolled out across Europe as an ecologically acceptable replacement for asphalt based pavements.

Another well reported “Biomaterial Blend” based ‘tarmac’ is provided by Ecopave Australia (Ref 40) which is not patented. The product called “GEO320™” bio-bitumen is available as a dry granulated material which is converted into Bio-asphalt at the hot aggregate mixing phase. The MRH version is said to be free of mineral oils and tars. Because the formulation and process is secret, it is difficult to form a picture of the raw materials used but they are said to include low molecular weight (molecular mass) materials such as sugar and molasses, natural tree and gum resins, natural latex rubber and vegetable oils, also suitable raw materials

are: palm oil waste, coconut waste, peanut oil waste, canola oil waste, lignin and cellulose, potato starch, rice starch and wheat starch. GEO320™ can also be made from the distillation bottoms (fractional distillation) of used/waste mineral oils.

Given the wide range of raw materials quoted and the declared ethical basis of the Ecopave Company, there may be a good case for approaching Ecopave as a potential partner in developing these alternative solutions.



Photo 6:
Vegecol application

The patent coverage of this field indicates that a very diverse range of mixtures or agricultural and forestry waste streams can be incorporated in the manufacture of non fossil fuel bitmac/tarmac substitutes. The patent situation should be professionally investigated. Superficially it appears to focus on North America and Europe, so Developing & Emerging economy clients may not be covered. It is also difficult to patent mixtures and processes with poorly defined chemistry, so existing patents may not prove to be an insurmountable barrier to progressing this raft of technologies.

5.2 Alternatives to Conventional Portland Cement based Layers

5.2.1 Pozzolanas as Cement Substitutes and other waste streams

Pozzolanas are materials containing reactive silica and/or alumina which on their own have little or no binding property but, when mixed with lime in the presence of water, will set and harden like a cement.

Pozzolanas are an important ingredient in the production of alternative cementing materials to Portland cement. Pozzolanas can be used in combination with lime and/or Ordinary Portland Cement (OPC). When mixed with lime, Pozzolanas will greatly improve the properties of lime-based mortars, concretes and renders for use in a wide range of building applications. Alternatively, they can be blended with OPC to improve the durability of concrete and its workability, and considerably reduce its cost (Ref 14).

A wide variety of siliceous or aluminous materials may be pozzolanic, including the ash from a number of agricultural and industrial wastes. Of the agricultural wastes, rice husk has been identified as having the greatest potential as it is widely available and, on burning, produces a relatively large proportion of ash, which contains around 90% silica.

130 million tonnes of rice husk could be potentially available annually on a global basis for pozzolana

production. As the ash content by weight is about 20%, there are potentially 26 million tonnes of RHA available as a pozzolana.

Rice husks have been used to fire kilns making bricks for road construction in South East Asia, (Ref 59) and if the combustion temperature were to be kept below 700°C then the ash could be used as a cement substitute for sub-base/surface strengthening or in bio-asphalt blends thus achieving a double benefit (Ref 46).



Photo 7:
Clay Brick production using rice husk fuel



Photo 8:
Laying burnt clay brick paving

For bulk processing, the Torftech Group has developed a novel application of its Torbed technology for the precise control of the combustion of rice husks to produce energy for industrial processes and a valuable ash by-product (Ref 15).

Many other waste streams provide pozzolanic materials, in particular Fly ashes (FA) from the combustion of coal and biofuels such as peat and wood (Ref 1), and potentially the sugar cane industry from bagasse combustion.

When pozzolanas are blended with other industrial waste stream materials, a range of geotechnical properties useful in road construction can be achieved. The properties of the different mixtures can be regulated by changing the proportion of different components (Ref 1, Ref 5).

Examples of such waste streams are:

- Fibre sludge (outcome: fibre-ashes)
- Process gypsum (outcome: gypsum-ashes)
- Stainless steel slag (outcome: slag-ashes).

Other waste streams which have been trialled for strengthening road pavement structures (Ref 2, Ref 4, Ref 6, Ref 51, and Ref 52) include:

- Waste bitumen instead of traditional cementitious or clay binders
- Steel slag
- Crushed glass
- Pulverised fuel ash (PFA)

- Incinerator bottom ash (IBA)
- Incinerated sewage sludge ash (ISSA)
- Eggshells
- From the paper industry:
 - Lime slaker grits
 - Lime slaker grits, mixed with sand
 - Green liquor dregs
 - Excess lime mud

By means of a trials programme, it should be possible to develop a range of OPC replacement and road base stabilising strategies depending on the local availability of waste streams in client countries, thereby reducing raw material costs, carbon footprint and stimulating local industry.

5.3 Geotextile and Biofibre Reinforcement

Approximately 2×10^{11} tons of lignocellulosics are produced every year world wide, so they are one of the worlds most abundant natural raw materials.

Geotextile separators have been successfully used for dust suppression in unbound gravel roads (Ref 53). Incorporation of biomaterials such as bamboo in road structures has been reported (Ref 51).

There is clearly a potential for the use of other natural fibres where available for example:

- Sisal is of particular interest in that its composites have high impact strength besides having moderate tensile and flexural properties compared to other lignocellulosic fibres (Ref 21).
- Coconut coir fibre
- Corn stover,
- Wheat, barley or rice straw
- Sorghum stalks
- Sugarcane bagasse
- Pineapple and banana leaves
- Hemp

Coir fibre has been trialled extensively as reinforcement within both conventional and blast furnace slag based mortars directed at low cost house building applications (Ref 54).

There is scope for development and invention of innovative low cost road construction materials by applying knowledge from the paper and pulp industry to tropical fibres and their incorporation in cement based surfaces. There is also scope for investigation of additives such as Black Liquor (lignin containing waste stream from paper pulp production) as an adhesive and modifier of cement/fibre systems (Ref 54).

6. Recommendations for Next Steps

This report is viewed as a preliminary initiative to revitalise interest in a topic that has considerable beneficial potential globally. It is timely to revisit past and ongoing work due to current real concerns regarding sustainable development, global warming and energy consumption and the more than 1 billion of rural poor people globally who are currently without even basic access and vital transport services. This report represents a start in what is intended to be a wide collaboration to improve and apply Eco-road knowledge. This initial knowledge review is not exhaustive in scope and detail; there are other potential individual and combination applications that could warrant consideration, such as shell fish residues, pozzolanas from brick production ash etc. This report serves as a discussion document to develop a number of very promising leads.

Unlike biofuels, many of the potential applications documented in this report involve a one-off application that will permanently lock carbon into the road structure.

Six technology areas have been identified as showing substantial promise for further consideration:

Group 1

- Wood or Palm Lignin
- Pine Resin or Tall Oil

Group 2

- Drying oils and Semi drying oils
- Oil, Resin and Biomaterial blends

Group 3

- Pozzolanas as Cement Substitutes and other waste streams
- Geotextile and Biofibre reinforcement

It is recommended that a series of creative workshops are run, each with a small group of experts covering the three groups of technology areas listed above. Ideally they would be held in different geographical areas with some overlap of the technical coverage to encourage expression of local knowledge and creativity. Each workshop would use the following general approach:

- List core problems seeking solution (causal chain analysis)
- Relevant knowledge input from materials experts
- Brainstorm possible solutions using technical stimulus from the information scan in Appendix 1
- Select a shortlist of solution technologies for further assessment
- Construct a knowledge gap matrix which identifies key unknowns requiring solutions in order to progress the project.

Following these workshops, proposals for research or development projects should be prepared for the topics with the most promising technical and economic benefits.

7. References

Note: Not all database reference documents are listed.

Ref 1 - Fly Ashes as flexible structural materials for low volume roads. Finnra Reports 70/2001 Pentti Latinen
<http://www.ceratechinc.com/>

Ref 2 - Non-traditional Binders for Construction Materials
J. P. Forth and S. E. Zoorob IABSE Henderson Colloquium, Cambridge, 10-12 July 2006

Ref 3 - Beets: A Biodegradable Bonus for Earth-Friendly Plastics? Agricultural Research/March 2008

Ref 4 - Paper industry by-products in Highway Construction and Related Applications (2007), Bill Thacker, NCASI, Feb 2007

Ref 5 - Fly ash facts for highway engineers. American Coal Ash Association. Michael Rafalowski 13/06/03
<http://www.tfhr.gov/hnr20/recycle/waste/index.htm>

Ref 6 - Beneficial Use of Industrial By-Products. National Council for Air and Stream Improvement (NCASI)12/2003

Ref 7- Control Of Dust Emissions From Unpaved Roads. Mohamad Succarieh, Assistant Professor of Civil Engineering, University of Alaska Fairbanks, AK 99775, May 1992

Ref 8 - Lignosulphonate for Dust Control and Road Stabilisation (brochure) Desert Mountain Corp. P.O. Box 1633 Kirtland, NM 87417

Ref 9 - Enzyme solutions as a soil stabilizer. Mihai O. Marasteanu, Ray Hozalski, Timothy R. Clyne, Raul Velasquez June 2005 Report No. Mn/DOT 2005-25

Ref 10 - Lance Seefeldt, USU professor of chemistry and biochemistry. Utah State University USU Biofuels Program

Ref 11 - Tasios Melis, unpublished. University of California at Berkeley

Ref 12 - New Agriculturist Nov 2007. International Centre for Research into the Arid and Semi-Arid tropics (ICRISAT).

Ref 13 - Seeds of change: Jatropha in India. November 2007 <http://www.new-ag.info/07/06/develop/dev3.php>

Ref 14 - Practical Action: Pozzolanas - Rice Husk Ash and Pulverised Fuel Ash http://practicalaction.org/practicalanswers/product_info.php?products_id=248

Also:

Rice Husk Ash Cement: Progress in development and application, R. Smith, IT Publications, London, 1984

Appropriate Use of Pozzolana Derived from Agro-waste Using Labour-Based Appropriate Technology, P. Nimityongskul & F. Gleeson

Concrete Incorporating Rice-Husk Ash: Compressive Strength and Chloride-Ion Penetrability, N. Bouzoubaâ & B. Fournier, July 2001, MTL 2001-5 (TR)

Ref 15 - Torftech Limited. 92 New Greenham Park Thatcham, RG19 6HW, Berkshire, United Kingdom

Ref 16 - "Overview on Bio-based Polyols for FPF Production", Phil Sarnacke, United Soybean Board

Ref 17 - Surface modification of mechanical pulp fibres with black liquor lignin fractions

Project at:

Wood Chemistry and Pulp Technology

Fibre and Polymer Technology

School of Chemical Science and Engineering

KTH - Royal Institute of Technology, Sweden

Research Leader: Professor Gunnar Henriksson

Ref 18 - Yellow Grease to the dust rescue. Render Magazine, 2820 Birch Avenue, Camino, CA 95709, May 2001

Ref 19 - Geotextile Separators for Dust Suppression in Unbound (Gravel) Roads, Transportation Research Record, 2007, Vol.1989, pp113-120

<http://trb.metapress.com/content/677g4075570312n2/>

Ref 20 - The Diesel Tree: Grow Your Own Oil. By Warren McLaren, Sydney on 04. 2.08 Science & Technology alternative energy

Ref 21 - A Review On Sisal Fiber Reinforced Polymer Composites. Kuruvilla Joseph, Romildo Dias, Tolêdo Filho R. Bras. Eng. Agríc. Ambiental, Campina Grande, v.3, n.3, p.367-379, 1999

Ref 22 - Project 12: Genetic screening of Jatropha curcas an important biofuel species of dry areas. The Institute of Wood Science and Technology (IWST), Bangalore [IWST/TIP/2003-2006]

Ref 23 - Biofibres from agricultural by products for industrial applications. Narendra Reddy and Yiqi Yang

Ref 24 - Henriksson et al. Cellulose Nanopaper Structures of High Toughness. Biomacromolecules, 2008; 9 (6): 1579 DOI: 10.1021/bm800038n

Ref 25 - Relative Effectiveness Of Road Dust Suppressants, Journal of Transportation Engineering, 1997, Vol. 123 No. 5, pp 393-397

Ref 27 - Patent No GB1379392
<http://www.wikipatents.com/gb/1379392.html>

Ref 28 - US Patent 5021476. US Patent Issued on June 4, 1991

Ref 29 - From the Colas website:
<http://www.colas.co.uk/colas-home.asp>

Ref 30 - United States Patent 6682593. Abstract: Application Number: 10/143689 Publication Date: 01/27/2004

Ref 31 - Iowa State University: Iowa State engineers hope to build better roads by using ethanol co-products - October 15, 2007.

Ref 33 - Midwest Industrial Supplies web Site
<http://www.midwestind.com/roadoyl.htm>

Ref 34 - US Patent 4822425 US Patent Issued on April 18, 1989

Ref 35 - From: The Lignin Institute Web Site
<http://www.lignin.org/>

Ref 36 - Tall oil Definition: <http://chemicalland21.com/>

Ref 37 - Drying oil. From Wikipedia, the free encyclopaedia

Ref 38 - Answers .com: Asphalt alternatives

Ref 39 - US Patent No 4419139. Publication Date: 12/06/1983

Ref 40 - Ecopave Australia Phone: +61 3 9395 1285 Mobile: 0431 218 632 mailto: ecopave@ecopave.com.au

Ref 41 - BMPs for Dust Abatement Practices on Unpaved County Roads in Oregon. Oregon Association of County Engineers and Surveyors. Adopted for Washington County DLUT Best Management Practices for Routine Road Maintenance

Ref 46 - Experiment of pavement suitable for rural transport. Dr Jasper Cook - Robert Petts, Bach The Dung - Pham Gia Tuan, Intech - TRL - WSPI - TEDI, LCS Working Paper No 16.

Ref 47 - University of Minnesota Technology Exchange, Summer 2001 <http://www.mnltap.umn.edu/Publications/Exchange/2001-3/dustcontrol.html>

Ref 48 - Dust control composition: US Patent 6589442
 Issued on July 8, 2003

Ref 50 - Q&A to Ecopave Australia on GEO320 Biobitumen MRH. Bioasphalt™, Biopave™ and Adhesives Technologies Sandra Lawson [Thursday 1 September 2005]

Ref 51 - NCASI Technical Bulletin No. 0931: Beneficial Use of By-Product Solids from the Kraft Recovery Cycle, 2007 (Report available to NCASI members only) www.ncasi.org

Ref 52 - NCASI Technical Bulletin No. 0655: Alternative Management of Pulp and Paper Industry Solid Wastes, 1993 (NCASI members only)

Ref 53 - European Patent EP1466878, United States Patent 20080006178 09/25/2007 Michel, Ballie (Montigny Le Bretonneux, FR)

Ref 54 - Vegetable Plants and their Fibres as Building materials. Second RILEM Symposium 1990

Ref 55 - World Enzymes Australia, now a division of Mitebridge Pty Ltd, <http://www.mite.com.au/>

Ref 56 - Patent: WO 2007070706 20070621 soil stabilization. Inventor Leigh I. Lmdenbaum

Ref 57 - Brazilian Journal of Chemical Engineering. J.D.Rocha, A.R.Coutinho and C.A. Luengo March 13, 2002

Ref 58 - Professor Ernst Berl of Pittsburgh's Carnegie Institute for Technology. Time Magazine (Monday, Sept. 23, 1940)

Ref 59 - Bach The Dzung, gTKP, Report on Rice Husk Fired Clay Brick Road Paving, Vietnam, November 2008

Ref 60 - Robert Petts, LCS Working Paper No 1, Rationale for the Compilation of International Guidelines for Low-Cost Sustainable Road Surfacing, Edition 3, March 2007.

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