The Efficient Use of Environmentally-Friendly Natural Rubber Latex in Road Construction - Past, Present and the Future

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Introduction

In the last decade the volume of traffic using roads in EU and RoW has increased sharply.

With increased reliance on roads for the speedy delivery of materials, and decline in use of rail network in developed countries for everyday freight transportation, the burden on many countries road system has increased dramatically.

Bitumen and its use as a binder for roads (Asphalt) has increased in line with this, as need for faster repair and maintenance and quieter roads has become necessary. Concrete roads although still in use today have become unpopular due to cost constraints during construction, difficulty in affecting repairs, poor drainage (Aquaplaning), and noise.

The burden placed upon road system has reached a critical stage in many developed and developing countries. The increased volume in heavy goods vehicles coupled with an appreciable increase in allowable axle weights for these vehicles, has lead to dramatic increase in level of stresses exerted on Asphalt surfaces. Furthermore congestion and economic costs of road maintenance has resulted in need to enhance asphalt performance by polymer modification.

In the past unmodified asphalts were able to cope with traffic volume and loads exerted on them, increasingly the durability of these surfaces have been put under scrutiny. Increased traffic loads, volumes and congestion have lead to sharp increase in problems with deformation (‘Rutting’) during Summer months and Cracking (Thermal, Reflective, and Load associated) during cold weather on asphalt roads.

In the last 20 – 30 years efforts have been made to enhance the durability of asphalt roads by introduction of polymers. The majority of research carried out in the last couple of decades has been with the use of Synthetic polymers (such as SBS, EVA, SBR, and Polyolefin). This is in part due to fact that Synthetic polymers used are made or can be added by the same companies that supply bitumen and their focus has been on the promotion of their own products.

However, before this time in the UK, EU and USA the use of NRL in asphalt had been studied extensively in the 1950’s and 1960’s. Today, NRL is still in use in the UK for construction of high performance asphalt surfacing and is still found to be an efficient polymer modifier for Asphalt surfacing.

The objective of this paper is to highlight past research into addition and use of natural rubber latex has on asphalt roads, the current products and applications where natural rubber latex is used today and how to stimulate greater demand for its use in the future.

Early Studies into the Use of Natural Rubber in Asphalt.

The first ever application of natural rubber latex in road construction took place in 1929 in Singapore. The great depression, war and slow recovery of global economy meant that it was another 20 years before researchers once again began to take an interest in Natural rubber latex in roads.
In UK, USA and South Africa, organisations such as the NRPRA (Natural Rubber Producers Research Association, UK)\(^1\) in cooperation with the government road research organisation’s like TRL (Transport Research Laboratory, UK) began to study the effects of NRL modification on Asphalt durability in road surfaces. Early studies assessed use of Natural Rubber Latex and Natural Rubber Powder (unvulcanised and lightly vulcanised).

These early studies in UK lead to the publication of a document: Road Note 36\(^3\)\(^4\).

Road Note 36 – Specification for the manufacture and use of rubberised bituminous road materials and binders was the point of reference used by the road industry for the preparation of pre-blended rubberised bitumen.

Pre-blended bitumen describes a technique whereby the bitumen and natural rubber are blended together and stored prior to their use in asphalt mixtures.

Road Note 36 refers to use of either Natural rubber latex or natural rubber powder (unvulcanised and lightly vulcanised).

Natural rubber powder was considered to be less popular than use of natural rubber latex due to fact that early experiments found that for natural rubber powder to have any beneficial effect on the modified asphalt the rubber must fuse with bitumen to form a ‘gel’ state\(^2\). To achieve the gel state it was necessary to heat bitumen to high temperatures and mix rubber and bitumen for up to as long as 2 hours to achieve homogeneity. In powder form the higher cost coupled with need to add higher dosage made natural rubber latex the product of choice.

Additionally, adding natural rubber latex was good in that the discrete rubber particles dispersed in the water phase ensured that rubber fused with the bitumen easily.

However adding water to hot bitumen did result in the bitumen foaming and the need for large quantities of steam to be evacuated from the bitumen. This required the use of specialised equipment (See Diagram 1). Furthermore the use of traditional centrifuged NR latex preserved with ammonia generated associated health and safety issues.

However there was commercially available, a speciality (‘Evaporated’) natural rubber latex with high solids content (68 – 73%) and preserved with a fixed alkali (LCS and Standard Revertex respectively), that reduced foaming and eliminated noxious ammonia fumes issues. These products also had added benefits of broader particle size distribution and retained natural antioxidants found in ‘field’ latex due to the method of manufacture (contained fine ps rubber particles not present in Centrifuged or Creamed NRL) that further enhanced products compatibility and performance in hot bitumen. This product consequently became the NRL product of choice for the asphalt producer.

However the preparation of NRL modified bitumen was limited to a few asphalt plants equipped to handle latex addition.

\(^1\) Anonymous – Rubber in Roads Fact Sheet Ref. no. RFS3 Published by NRPPRA
\(^2\) L. Mullins; A.R. Sme – More About Rubber in Roads. Published by The British Rubber Development Board April 1953.
\(^3\) D. J. Lyons – Road Note 36 Specification for the Manufacture and Use of Rubberised Bituminous road materials and binders. Published by HMSO 1964 (1\(^{st}\) Edition)
\(^4\) P.D Thompson - Full Scale Road Experiments Using Rubbersied Surfacing Materials. Published by HMSO 1964.

It was found that storage of pre-blended natural rubber latex had one disadvantage in that at high temperatures (>120°C) heat caused the thermal degradation of natural rubber reducing its effectiveness on the binder properties of the asphalt. A table giving maximum storage time versus storage temperature was developed to help user’s as part of this guide.
The storage issue coupled with fact that in general the need for polymer modification of bitumen to cope with traffic volumes in UK in the 1950/60's resulted in limited use of technology for only high stress locations or prestigious locations in the UK.

**Improvements in Natural Rubber Latex Addition**

With the economic boom of the 1960’s, increased traffic volumes, increased use of Heavy goods vehicles (HGV’s), and repair/upgrade of road network built in 1940/50’s and the continued research efforts of NRPR/A/TRL. Asphalt manufacturer’s devised method to blend NR (Both Powder and Latex form) into bitumen during the preparation of the asphaltic concrete to overcome storage stability, foam, and steam evolution problems manufacturers experienced earlier with bitumen modification.

The process developed suited Natural rubber in latex form although concept was originally designed for use of latex and powder natural rubber (i.e. the difference was that for the NR powder the mixing had to be increased more to ensure homogenous blending.

The method for adding NR latex** to bitumen was very simple (Diagram 2). The process uses the traditional batch asphalt mixing plant (known as a ‘Pugmill Mixer’) and has the benefit that in relative terms the volume of bitumen and latex added to the mixer is less than 10% of the total mix (by weight). The majority of mix is aggregate/ Crushed sand and filler (90-95%), Bitumen (4-9%) and NR latex (<1%).

As with the previous process the

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** The system also benefited from availability of High Solids Evaporated Natural Rubber Latex (Revertex) that was stabilised using fixed alkali (instead of Ammonia). These products are available with solids contents of 68% or 73% solids, reducing steam emissions and problems with ammonia fumes.
The addition system is carried out in 3 main steps and these are:

1. The hot graded aggregate, sand and filler are charged into mixer (approx 30 –45 seconds).
2. The hot bitumen is then added to mixer and mixed to evenly coat aggregate (10-15 Seconds).
3. The latex is then Sprayed/ charged at required dosage into the mixer and mixed thoroughly (5-10 seconds).

The above methods from the following advantages that allows system to work:

- The amount of foaming** is minimised due to relatively small volume of bitumen in mixer.
- The NR latex reacts quickly with bitumen because it is a discrete dispersion of rubber that ‘gel’ quickly with bitumen.
- The amount of steam is relatively small and fumes given off are low.
- Mixing time for asphalt is only increased by 10 – 15 seconds compared to 1 – 2 minutes for NR powder.
- Using fixed alkali** rather than ammonia to stabilise NRL ensures that no noxious fumes are given off during mixing.

This method of production of NRL modified is still in use in UK, South Africa, India and some EU countries today.

The cost of installing equipment to meter latex into asphalt plant is inexpensive and is easy to clean and maintain.

With the development of the above process the wider use of NRL in asphalt became simpler and allowed it greater use and development.

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As a result of the improvement in production method an increase in the number of projects assessing the performance of polymer modification took place in the 1970’s to assess the affect that rubberised bitumen had on road materials\(^1\). Many later reports on how natural rubber latex can enhance the performance of asphalt road materials were also written\(^2\)\(^3\)\(^4\)\(^5\). The reports highlighted the benefits of natural rubber modification of bitumen in many different types of surfacings such as Hot Rolled Asphalt (HRA), Porous Asphalt, etc…

**Natural Rubber Latex in Bitumen Emulsions.**

All the above research was focussed on use of Natural rubber latex in hot bituminous materials however in the 1960’s/1970’s researchers in EU were developing new road surfacing systems using bitumen emulsions.

Bitumen emulsions had been in use in road construction since the 1920’s, however the emulsions were stabilised using anionic emulsifiers or by saponification of the naturally occurring organic acids present in the bitumen. These formed stable bitumen emulsions, however the time in which the emulsion dried was determined by the ambient conditions making their use limited to industrial applications such as roofing.

During the 1950’s, researchers developed new bitumen emulsion systems where surfactants were used to produce cationic bitumen emulsions. Cationic emulsions had the benefit the cationic (+vely charged) bitumen emulsion when it came into contact with the anionic (-vely charged) mineral aggregate the emulsifier were attracted to mineral surface, the charge neutralised and emulsifier loses it solubility and ‘breaks’ (coagulates). The ‘breaking’ of emulsion leads to good bitumen aggregate adhesion and speeds up development of bitumen aggregate adhesion without need for full drying of material.

By careful selection of the type of bitumen, emulsifier type, water content, etc.. it is possible to tailor the behaviour of a cationic bitumen emulsion to suit a variety of end uses.

The development of cationic bitumen emulsions allowed new surfacing systems to be developed that formed a new range of road surfacing processes described as ‘cold mix’ applications. These new road surfacing techniques also required performance enhancement and polymer modification of bitumen emulsions also became necessary.

As with hot bitumen modification the benefits of natural rubber latex modification were well established and it made logical sense to try modification of bitumen emulsions using natural rubber latex.

Early developments in polymer modified cationic bitumen emulsions developed a mechanism whereby normally anionic natural rubber latex can be made compatible with cationic bitumen emulsions and then can be blended with bitumen as part of the aqueous phase during bitumen emulsification.

This patented process/system was developed in the 1970’s and is known as the ‘Ralumac’ process. This process is still in widespread use in EU and rest of world.

The Ralumac process has one disadvantage in that the NR latex must be prestabilised prior to its mixing with aqueous phase to prevent destabilisation. In certain bitumen emulsion plants this is not

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3. D. Williams; P. Whiteley – Rubberised Asphalt on Concrete Roads. Published in Queens Highway, no 106, April 1976

Seminar “Rubber in Transport”, Breda, The Netherlands, 9-12-2004
Joint initiative of the BPRI and the VKRT.
possible (e.g. Continuous emulsion plants) where additives are metered individually rather than preblended together in separate tank (See Diagram 3).

However, some companies have devised their own systems and use a ready to use cationic natural rubber latex (i.e. 1497C Plus Revertex, made by Revertex Malaysia Sdn Bhd.).

Using natural rubber latex that has already been made compatible with cationic bitumen emulsion means that polymer can be added ‘pre’ or ‘post’ emulsification of the bitumen (See Diagram 3) allowing greater process flexibility.

Interestingly the effects that natural rubber latex modification has on performance of bituminous road materials is identical despite fact that in Bitumen emulsion applications the bitumen and NR latex remain as separate discrete particles up until the emulsion breaks when they are absorbed onto aggregate surface.

The ability to add natural rubber latex pre or post addition makes it easier to adapt existing bitumen emulsion plants to allow polymer modification.

At present natural rubber latex modified bitumen emulsions are used predominantly for use in micro-surfacing, surface dressing and tack coats.

![Diagram 3: Typical Bitumen Emulsion Plant Incorporating Latex Addition](image)

**Effect of Natural Rubber Latex on Performance of Asphalt Road Materials.**

Natural rubber latex modification of bitumen since its original introduction has been found to enhance the thermal stability of asphalt in two fundamental ways:

- Natural rubber latex at high temperatures increases the bitumen’s viscosity (thickening) making road surface more resistant to deformation under heavy loads during hot weather.
- At low temperatures the natural rubber reduces thermal cracking associated with bitumens.
As a result of this road surfaces are resistant to defects and durability of a road surface is increased markedly.

The reason for this alteration lies in fact that natural rubber latex and other polymers alters the rheological properties of the bitumen. Bitumen is a visco-elastic liquid whose viscosity changes with temperature and shear (load).

At low temperatures bitumen freezes and becomes so stiff that it will crack under stress. Natural rubber acts like an elastic band and hold bitumen together and helps dissipate stresses as they develop.

As temperature increases the bitumen’s rheology changes and begins to flow. However the polymer acts like a membrane and resists the flow of the bitumen increasing it resistance to shear.

Another factor that was first observed in 1960’s but could not be explained by the traditional empirical measurements used to determine properties of bitumen (Such as Ring and Ball softening point and Penetration), was the ability for natural rubber latex modified bitumen to ‘self-heal’ if thermal cracking had occurred during cold weather, when temperatures improved.

This once again was linked to fact that natural rubber form a 3 dimensional network within bitumen and if bitumen cracks the rubber hold the bitumen in place until temperature recovers sufficiently to allow bitumen to fuse back together. This effect made the use of Natural rubber latex modified asphalt popular in 1970’s, as an overlay onto existing concrete roads. ‘Reflective’ cracking across expansion joints in the original concrete road caused by ground movement, vibration and thermal expansion/contraction lead to severe cracking in unmodified asphalt overlays. However research proved that an overlay consisting of a NRL modified base and wearing course applied over concrete pavement did not crack even after it had been applied for more than 5 years whereas visible cracks appeared after only 1 year in an unmodified section¹.

The stress absorbing properties of natural rubber latex modified bitumen also makes it ideally suited for use in applications where bitumen emulsions are used.

Emulsion based road surfacing are normally applied as thin (<30mm thick) overlays over existing road wearing course. As a result the coating is subjected to severe shear forces and adhesion between coating and old road surface is critical. Hence the elastic properties that natural rubber latex imparts to the bitumen allows the these high stresses to be absorbed without loss of adhesion to background or aggregate.

These stresses are highest when the road surface is cold and emulsion based systems are prone to damage during Winter months due to combination of wet and cold weather conditions. Natural rubber modification has been found to be successful at preventing cracking at low temperatures in hot asphalt as described earlier, and same factors are affecting both systems.

The biggest challenge that prevents the more extensive use of natural rubber latex and other forms of polymer modified bitumens used in road construction is the lack of performance tests that accurately demonstrate the affects that polymer modification has on bitumen.

Many modern techniques have been developed since the 1970’s to compliment the traditional tests used to characterise bitumen (Softening point (Ring & Ball), penetration, Fraass Brittle point, Ductility, RTFO Aging etc).

Unfortunately, many of these tests were developed long after much of the original research into Natural Rubber Modified Bitumen in road materials was made, and modern research has focussed on new synthetic polymers.

¹ W.S Szatkowski – RRL Report LR308 Resistance to Cracking of Rubberised Asphalt: Full Scale Experiment on Trunk Road A6 in Leicestershire. Published by Road Research Laboratory, 1970.
The new tests used are based upon Rheological measurements on the modified bitumen (Dynamic Shear Rheometry, Bending Beam Rheometer, Elastic Recovery, Direct Tension Testing,...) but ignore other areas such as adhesion or aggregate cohesion in the overall performance of the asphalt.

These techniques do provide greater understanding of the binders (Bitumen) behaviour under shear, but in some instances the new tests have limits set that only accurately describe the new modern polymers offered in competition against Natural Rubber, and is leading to NR exclusion in some markets through lack of understanding.

Natural rubber latex has already demonstrated its performance through its effective use in early field trials and has stood the test of time and changing traffic conditions and working practices since the 1970’s.

There is no data available that suggests that Natural Rubber latex is not an effective bitumen modifier for road construction, and in UK, India and Asia it continues to demonstrate its performance in hot bitumen. Furthermore it continues to be widely used as a modifier in bitumen emulsions and is used extensively in EU, USA, South Africa, India and Asia.

In Asia, the concern is that adoption of performance tests and specifications may result in NR’s exclusion from road construction, if limits are strictly adhered to without understanding the limitations of these tests to quantify Natural Rubber modified bitumen performance (See Table 1 and 2).

### Independent Laboratory Test Data on 1497C (ex. Polish Road Ministry, IBDiM)

- **Emulsions Used:**
  - Type: K1-70 (4.3% m/m 1497C)  K3-60 (4.2% m/m 1497C)
  - Formulation: 64.91% Asphalt 171 Pen.  59.52% Asphalt 125 Pen
  - 5.09% 1497C  4.51% 1497C
  - 0.23% Emulsamine L60  0.8% Polyril L-80
  - 0.15% HCl (36%)  0.5 HCl (36%)
  - 29.62% Water  34.77% Water

Prepared emulsions and the respective recovered binders were tested in accordance with Polish and EN standards.

The threat that natural rubber latex may be excluded due to laboratory specifications that do not accurately demonstrate polymers ability to perform is real, and could jeopardise the future use of NRL in road construction, other than as a filler/partial modifier in Crumb rubber modified asphalts (e.g. USA, Canada, Malaysia) or in specialist hot bitumen applications and emulsion systems that are approved due to past field trial experiments.
1497C gave excellent performance in both emulsion types.

Only exception was in terms of elastic recovery in K1-70 type emulsion where 1497C did not meet minimum requirements.

However, Vialit results do not suggest that 1497C use will lead to premature road failure at low or high temperatures.

### Recovered Binder Properties:

<table>
<thead>
<tr>
<th></th>
<th>K1-70</th>
<th>K3-60</th>
<th></th>
<th>K1-70</th>
<th>K3-60</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1497C</td>
<td>Spec</td>
<td>1497C</td>
<td>Spec</td>
<td></td>
</tr>
<tr>
<td>Penetration, dmm</td>
<td>110</td>
<td>70 - 240</td>
<td>85</td>
<td>70 - 240</td>
<td></td>
</tr>
<tr>
<td>Softening Point (R&amp;B), °C</td>
<td>44</td>
<td>≥ 42</td>
<td>56</td>
<td>≥ 17</td>
<td></td>
</tr>
<tr>
<td>Flow, °C</td>
<td>-21.5</td>
<td>≥ -15</td>
<td>-18.5</td>
<td>≥ -15</td>
<td></td>
</tr>
<tr>
<td>Elastic Recovery @ 25°C, %</td>
<td>35</td>
<td>≥ 60</td>
<td>51</td>
<td>&gt; 40</td>
<td></td>
</tr>
<tr>
<td>Vialit Cohesion @ -15°C, % m/m</td>
<td>100</td>
<td>≥ 70</td>
<td>95</td>
<td>&gt; 40</td>
<td></td>
</tr>
<tr>
<td>Vialit Cohesion @ 60°C, %m/m</td>
<td>100</td>
<td>≥ 100</td>
<td>100</td>
<td>&gt; 80</td>
<td></td>
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</tbody>
</table>

What Types of Asphalt Surfacing Can Benefit from Natural Rubber Modification.

The number of different types of road surfacing that natural rubber has been successfully used and are still used up to present day are:

- **Hot Bitumen Modification:**
  - Hot Rolled Asphalt (HRA but Also known as Asphalitic Concrete).
  - Porous Asphalt (or Pervious Macadam)
  - Stone Matrix Asphalt (SMA)
  - Base Course
  - Rolled Asphalt applied over existing concrete pavements

- **Cold Mix (Emulsion) Modification:**
  - Micro-surfacing
  - Surface Dressing
  - Tack Coats
  - Soil Stabilisation

At present natural rubber latex is predominantly used in Micro-Surfacing and Hot Rolled Asphalt.

Porous asphalt and SMA are relatively new surfacing techniques that have been developed to deal with problems of noise and deformation (rutting) respectively that are major issues in UK, EU and USA.

These modern asphalts benefit from NR modification not only because of NR's positive effects on low and high temperature resistance and aging, but it provides added benefit of preventing the hot bitumen from draining off aggregate during its transport from the asphalt plant to the road site.

SMA and Porous Asphalt differ from the traditional Hot Rolled Asphalt materials, in that they are gap graded (Aggregate is not continuously graded by sizes) producing an Asphalt surface that contains
voids that would normally be filled by fine sand and filler. The presence of sand and filler in traditional mix designs helps increase viscosity of binder and prevents bitumen from sagging in hot state on the stone during transit to road site.

In SMA and Porous Asphalt there is very little sand and filler in asphalt so viscosity of bitumen is reduced making it difficult to prevent binder from draining from aggregate. As a result without any modification it is only possible to add approx 4 – 4.5% by weight of bitumen into the Asphalt. This is too low and results in poor durability under heavy traffic loads. However the addition of NR Latex has been found to increase wetting and viscosity of the bitumen at high temperatures preventing binder drainage even at or close to the optimum bitumen contents of 6 – 6.5% bitumen. Other modifiers can also achieve this as well as fibres, but NR latex was found to be most effective in UK trials for Porous Asphalt\(^1\) (See Graph 1 and Table 3).

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
Aggregate Mix & Binder Drainage: & \\
\hline
% Passing & Binder & 100 Pen. + 3\% LCS \\
\hline
14mm & 60.7 & 7.0 & 6.8 & 1.5 \\
10mm & 99 & 6.5 & 5.3 & 0.2 \\
Dust & 21.6 & 6.0 & 4.0 & 0.0 \\
Filler & 7.8 & 5.5 & 1.9 & 0.0 \\
\hline
\end{tabular}
\caption{Table 3}
\end{table}

The data demonstrates how natural rubber latex can have added benefits when used in certain specific applications.

Another interesting area of interest is in the use of NRL modified bitumen emulsions to stabilise and form low cost temporary road surfaces in developing countries. The concept is that a road can be made efficiently by removing top layer of existing soil, compacting sub-base and then mixing the removed soil and mixing soil with a natural rubber latex modified bitumen emulsion, laying the mixed soil and emulsion, and finally compaction using a pneumatic or steel roller. This forms a durable road surface that is water resistant, can tolerate medium/heavy good vehicle traffic (low volume) and is resistant to cracking and deformation.

This system is already being promoted in areas of Far East as temporary road surface on plantations and in developing countries where replacement of mud tracks is required to provide better access to remote areas.
Relative cost of the system is low and only requires supply of paving equipment (planer, sprayer, paver and roller) and NR modified bitumen emulsion.

**The Future of Natural Rubber Latex Modified Bitumen in Road Construction.**

Natural rubber latex has a proven track record as an effective polymer modifier for bitumen in road construction gained within UK, EU, USA and Asia over the past 40-50 years.

However, it’s continued use is under threat from synthetic polymers who have invested heavily in the development, promotion and marketing of these often less environmentally friendly and more expensive alternatives.

The development of new laboratory techniques for assessment has also created an opportunity for these new polymers to demonstrate differences that do not necessarily equate to improvements in performance in the field.

Natural rubber latex has also proven to be more cost effective than the use of natural rubber powder or recovered scrap tyres due to higher rubber dosage, higher processing cost, preparation and
storage stability. Furthermore the variability of composition of a recycled waste material such as scrap tyre rubber also makes consistency a very real concern.

Natural rubber latex and modified versions for use in bitumen emulsions allows road industry to provide an efficient, safe, ecologically sound alternative to other polymer modifiers that improve the durability and life of asphalt road surfaces.

There is a real risk that natural rubber latex’s use in road construction will become marginalized unless NR producing nations begin to promote and make use of a locally available resource to improve their road network.

It is clear that in EU and USA the use of polymer modified bitumen and bitumen emulsions for repair and new road construction has increased as benefits of polymer modification to their economies has become quantifiable due to cost of road maintenance, traffic congestion and accidents. Increasing the life expectancy and reducing frequency or repair and maintenance costs of a major trunk road have proved that polymer modification pays for itself in long term.

There is an opportunity for developing countries to learn from the West’s mistakes and to improve the quality of their road networks by making greater use of polymer modified asphalt and benefit their local economies by greater use of a local natural resource.