TECHNOLOGIES FOR THE RAY

JULY 2018

VERSION 4

Innovia TECHNOLOGY

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ROADMAP FOR THE RAY

THE PROBLEMS

RESOURCE EFFICIENCY

Gasoline for vehicles, bitumen for the road, and electricity for lighting all deplete the earth's fossil fuel reserves

Burning these fossil fuels releases carbon dioxide into the atmosphere and causes global climate change

Concrete also has a large carbon footprint

Quarrying for road materials scars the landscape and damages local ecosystems

POLLUTION REMEDIATION

Local pollution from vehicles - NOx, SOx, particulates

Ground water pollution - toxic chemicals, motor oil, particulates and road materials

Litter and road debris

WILDLIFE CONSERVATION

Roadkill

Habitat degradation and fragmentation

Noise pollution

Light pollution

LIFE SAFETY

Accidents, injuries and fatalities

ECONOMIC COSTS AND LOST OPPORTUNITY

Financial cost of accidents

Congestion and prolonged travel times

Maintenance costs

THE RAY PROJECTS

- SOLAR POWER
- SUPPORTING ELECTRIC VEHICLES
- PAVING AND INFRASTRUCTURE MATERIALS
- DATA AND MONITORING
- WILDLIFE CONSERVATION
- LIGHTING THE RAY
- EXPERIENCE OF STOPPING

THE RA

LARGE SOLAR FARM AT

PV4EV CHARGER

RUBBER MODIFIED ASPH

AMBIENT POLLUTION M

LESS MOWING

REPLACE ALL MERCURY OR S
WITH THE LATEST LED OR LI

AY 2017

EXIT 6

HALT

ONITORING

SODIUM LIGHTING ON THE RAY
EP TECHNOLOGY

THE RAY 2018-2019

SOLAR NOISE BARRIER AND SOLAR POWERED LIGHTING ON WEST POINT BRIDGE

HYDROGEN REFUELLING STATION

ASPHALT BINDER FROM HOG MANURE

SOLAR AUTONOMOUS SENSOR NETWORKS

BIOSWALES

PILOT SOLAR POWERED LED LIGHTS ON THE BRIDGE AT EXIT 6

DRIVE THROUGH TIRE PRESSURE MONITORING AND INFLATION

SOLAR CANOPIES IN PARKING LOTS

LOW CARBON CONCRETE

VEHICLE EMISSIONS MONITORING

FENCES AND CULVERTS

TRIAL A SMART SYSTEM OF INTELLIGENT ROAD STUDS ON A SHORT STRETCH OF HIGHWAY

THE RAY 2020

GLARE REDUCING CENTRAL HIGHWAY BARRIERS

ELECTRIC VEHICLE CHARGING LANE

LANDFILL MINING FROM LAGRANGE LANDFILL

POLLUTION MONITORING RAY GATE

FULLY SERVICED REST STOP

HOW MIGHT WE ACHIEVE ZERO?

RESOURCE EFFICIENCY

Electric vehicles are recharged with renewable electricity

Hydrogen fuel cell vehicles are filled with renewable hydrogen

Induction coils in the road, or overhead conductors, provide power for electric vehicles on the move

POLLUTION REMEDIATION

Electric or hydrogen fuel cell vehicles emit no local pollution

Changing attitudes make dropping litter socially unacceptable

WILDLIFE CONSERVATION

A connected network of vehicles and sensors detect wildlife and avoid collisions

Plentiful fences, culverts and wildlife bridges eliminate wildlife crossings

Autonomous vehicles require no illumination either on the vehicle or the road, eliminating light pollution

Electric or hydrogen fuel cell vehicles emit little noise. Might a breakthrough in tire design or road surface eliminate noise?

LIFE SAFETY

Autonomous vehicles are less likely to crash

ECONOMIC COSTS AND LOST OPPORTUNITY

No further road building or expansion is necessary as autonomous vehicles use narrower lanes and can drive closer together, radically increasing capacity and reducing congestion

Huge economic potential is unlocked as fast autonomous vehicles eliminate congestion and radically reduce journey times, all on the same installed infrastructure

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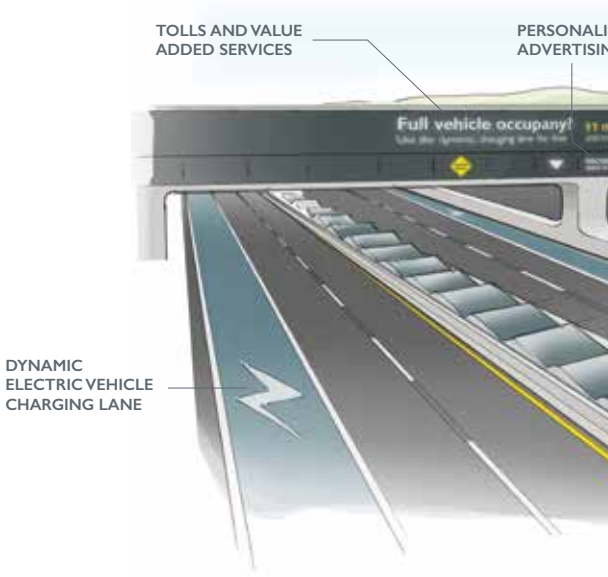

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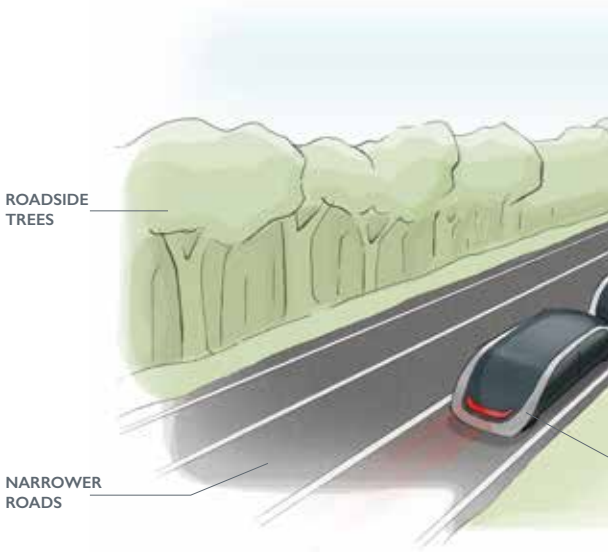

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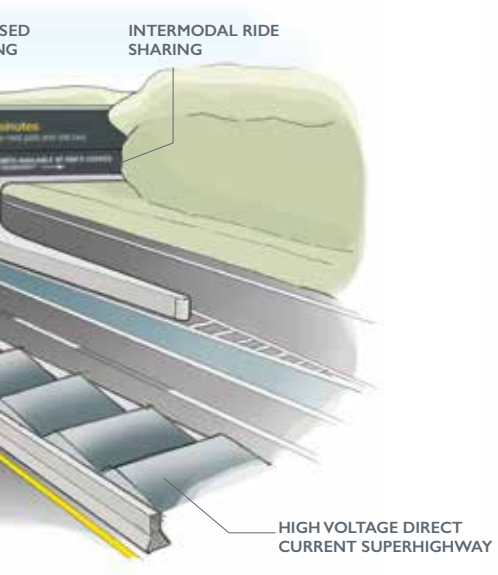

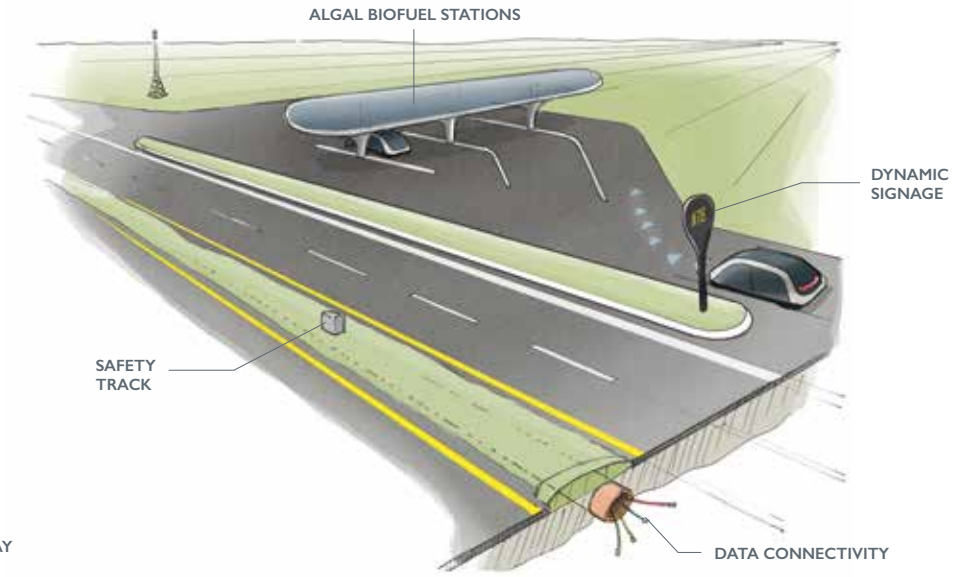

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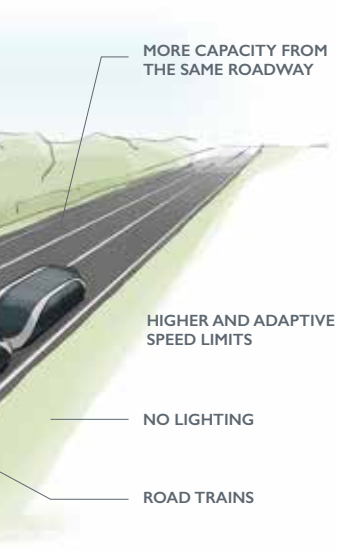
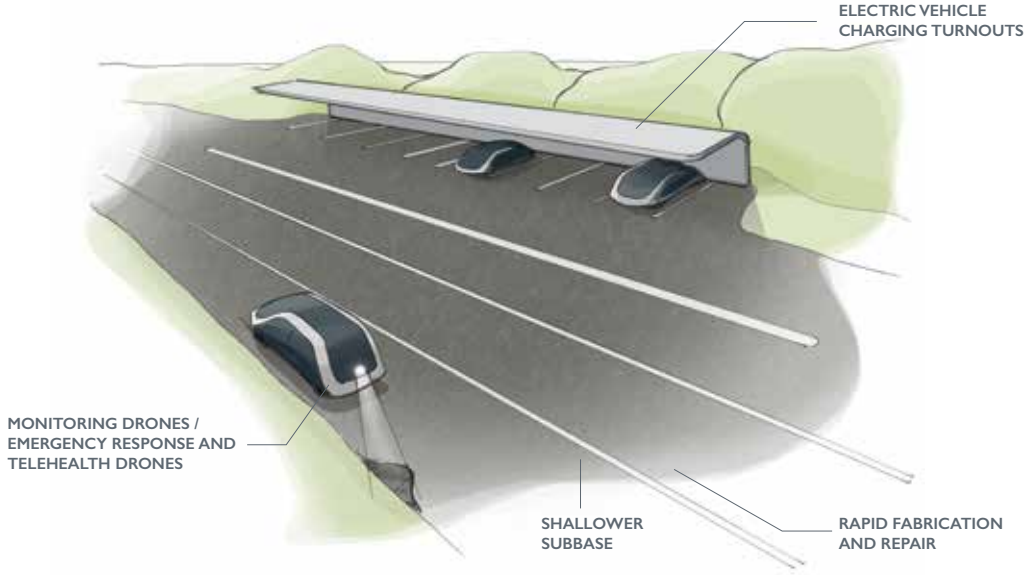




TECHNOLOGY ASSESSMENTS AND RECOMMENDATIONS

We have assessed the technologies in the MZC Executive Summary document for:

SUSTAINABILITY

Must have a real and positive sustainability impact.

And no significant adverse impacts.

FEASIBILITY

Must have the potential to work.

What are the technical challenges? Is it TRL 5-6?

Does it have long-term mass market commercial potential
i.e. could it ever be cost effective, and is it scalable?

CAN THE FOUNDATION HELP MAKE IT HAPPEN?

Is it relevant to the I-85?

Is it achievable by the Foundation?

Can it tell a great story?

Could it attract additional investment dollars?

Does it have the potential to inspire change beyond The Ray?

Would it be financially scalable beyond the The Ray?

TECHNOLOGIES WE RECOMMEND FOR THE RAY:

Solar power
Supporting electric vehicles – PV4EV charger, EV charging lane, e-Highway
Biogas from anaerobic digestion
Novel paving and infrastructure materials - recycled asphalt, bio-binders for asphalt, low carbon concrete
Data and monitoring (starting with pollution monitoring)
Wildlife conservation measures – mowing less, bioswales, fences, culverts
Energy efficient lighting
Drive through tire monitoring and inflation

TECHNOLOGIES WE DO NOT RECOMMEND FOR THE RAY:

Atmospheric carbon capture
Piezo-electric energy generation
Wind power - macro, micro, from traffic
Biofuels – 1st (corn, rapeseed), 2nd (cellulose) or 3rd generation (algae)

DATA AND MONITORING

- Innovia recommends pollution monitoring on The Ray as a crucial first step in measuring and demonstrating the impact of interventions to key stakeholders
- We believe that this first stage of pollution monitoring can be achieved using established technology and pursuing the standards used by the EPA Ambient Air Monitoring Networks
- As a second stage, emerging technologies can be deployed on The Ray to permit vehicle-specific emissions monitoring, for immediate feedback to road users and long-term analysis of roadway emissions
- Innovia proposes a staged integration of sensors into the roadway. In addition to fixed sensors on newly constructed infrastructure, reconfigurable sensors and mobile sensors can offer targeted data without high upfront investment
- The Ray offers an environment in which the impact of highway safety measures can be tested and evaluated for effectiveness in reducing frequency and severity of accidents as well as cost-effectiveness
- All monitoring technology offers a valuable opportunity to engage the public through collection of crowdsourced data, real-time feedback and transparent online reporting

In an increasingly data-driven world, deployment costs have fallen for large scale monitoring. The use of large datasets to inform decision makers and engage consumers will be a major tool in planning future infrastructure. Monitoring strategies broadly fall into four categories:

- **Pollution monitoring** – the impact of the highway and of individual vehicles
- **Infrastructure monitoring** – the condition of the highway and any associated structures
- **Monitoring for safety** – observing incidents and driver behavior; driving compliance and encouraging safer driving
- **Data for value-added services** – consumer data to generate added value for road users and revenue for The Ray

The principal focus of this section will be on pollution monitoring.

POLLUTION MONITORING

A range of mature and emerging technologies can measure pollution along the roadway. The principle pollutants to measure are airborne pollutants, waterborne pollutants, light and noise. In addition, a range of newer technologies are emerging to extend detection to individual vehicles.

AIR POLLUTION

AMBIENT AIR POLLUTION MONITORING

Key pollutant gases on the roadway include carbon dioxide, nitrogen oxides (NOx) and sulphur oxides (SOx). In addition, incomplete combustion of fuels also leads to carbon monoxide and hydrocarbon emissions, and the interplay of the latter with NOx emissions influences ozone generation. Finer particulate matter, PM2.5 (under 2.5 micron diameter), is generated through combustion whilst coarser particulates, PM10 (2.5-10 micron diameter), may be dispersed from the road by vehicles. The benefit of measurement and targeted reduction of harmful emissions can be seen in the successful elimination of tetraethyllead as a gasoline additive, which has already saved a generation of children from elevated risk of cognitive impairment [1,2]. Similar progress has been made with carbon monoxide.

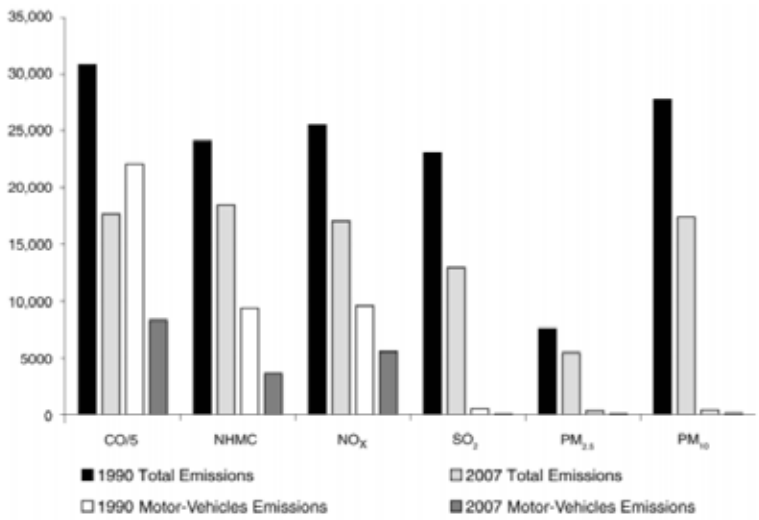


Figure 1: Progress in reducing air pollutant emissions in 1000 tons [10]

In addition to acid rain and climate change, roadside air pollution is a cause of asthma and is associated with loss of lung function and cardiovascular mortality [10]. Approximately 4% of US homes are estimated to be located within 150m of a major highway, where pollutants significantly exceed background [11].

Measurement of average air pollution levels can be achieved using low-cost mature technologies. As an initial step for The Ray, it would be inexpensive to deploy these established sensor technologies for weekly or monthly averages in order to measure the overall impact of roadway operations. Examples of established technologies include:

- diffusion tubes (NOx, SOx, ozone), and other adsorbents, which concentrate pollutants to allow for estimates on a 2-4 week basis, through collection and laboratory analysis;
- laser scattering for detection of particulate matter in real-time;
- UV, IR and visible absorption spectroscopy to measure carbon monoxide and ozone in real-time; and
- fluorescence spectroscopy to measure SOx and NOx in real-time.

As mandated by the Clean Air Act, the EPA maintains a list of limits for its criteria pollutants and maintains Ambient Monitoring Networks nationwide [3,4]. The Georgia Environmental Protection Division coordinates the monitoring network in the state including urban near roadway monitoring on I-85 in Atlanta [5]. Initially, using the existing ambient monitoring network as a model for The Ray, would ensure direct comparability of data and guarantee appropriate coverage. A full list of technology and reference standards for monitoring is published by the EPA [6]. The EPA is also trialing public engagement with daily data through the Air Now website and mobile apps [7].

VEHICLE EMISSIONS MONITORING

The next generation of monitoring technology uses novel spectroscopic techniques to measure emissions of single vehicles.

The AccuScan system from Enviro Technology Services (Stroud, UK) uses UV and IR laser spectroscopy for detecting carbon monoxide, carbon dioxide, hydrocarbons, nitric oxide and particulate matter in under a second [36]. The system consists of a laser/detector system on one side of the road and a mirror on the other. The whole system can be connected using WiFi or cellphone data networks. At present, AccuScan can also be deployed in vans and is often used at on-ramps where engine strain is higher. The technology has been deployed in Colorado and several other US states as part of a rapid emissions testing program [39].

An alternative approach is open path Fourier-transform infrared spectroscopy (FTIR). This technique measures a wide range of wavelengths that vary over time to measure a distinct signature for different pollutants simultaneously. This method has been applied to ambient aircraft and roadway emissions by companies such as Kassay Field Services [37] and is being developed for emissions monitoring in Madrid [38].

Innovia recommends pursuing AccuScan systems for The Ray. Information from individual vehicle emissions monitoring can be provided to the drivers in real-time via roadside displays as in the Clean Run program in Western Australia [40]. If this technology were combined with automatic number plate recognition, owners could be notified if their vehicles exceeded the emissions limit, so they would take attention. Aggregated data on specific vehicle models can be conveyed to the authorities and potentially displayed in a transparent manner on The Ray website.

Figure 2: Enviro Technology Services AccuScan system [36]

Figure 3: Display from the Clean Run emissions monitoring program in Western Australia [40]

WATER POLLUTION

Changes in vehicle standards and improved filtration of run-off water may reduce the magnitude of water pollution and degree of water-course infiltration along The Ray. Pollutants include motor oil, heavy metals and road materials, and these can have a significant impact on soil and river ecosystems. A range of sensors could be installed in culverts and drainage systems around the highway. Libellium has launched a wireless sensor platform that can detect pH, dissolved oxygen, oxidation-reduction potential, conductivity, turbidity, temperature and specific halides, nitrates and metal ions [33].

LIGHT & NOISE POLLUTION

Vehicle headlights and fixed lighting both contribute to overall light pollution, which has grown rapidly as shown in the figure below. The principal detrimental impact of light pollution on human health is sleep disorders caused by a disruption of the circadian rhythm [8]. In particular, the wavelengths of light with the strongest impact are shorter than 550 nm (blue-green range) [9]. Consequently, for a given luminance, yellow sodium-vapor lamps (maximum emission at 588 nm) are less disruptive than most other forms of streetlights, such as mercury vapor lamps, incandescent bulbs and white light LEDs. It is

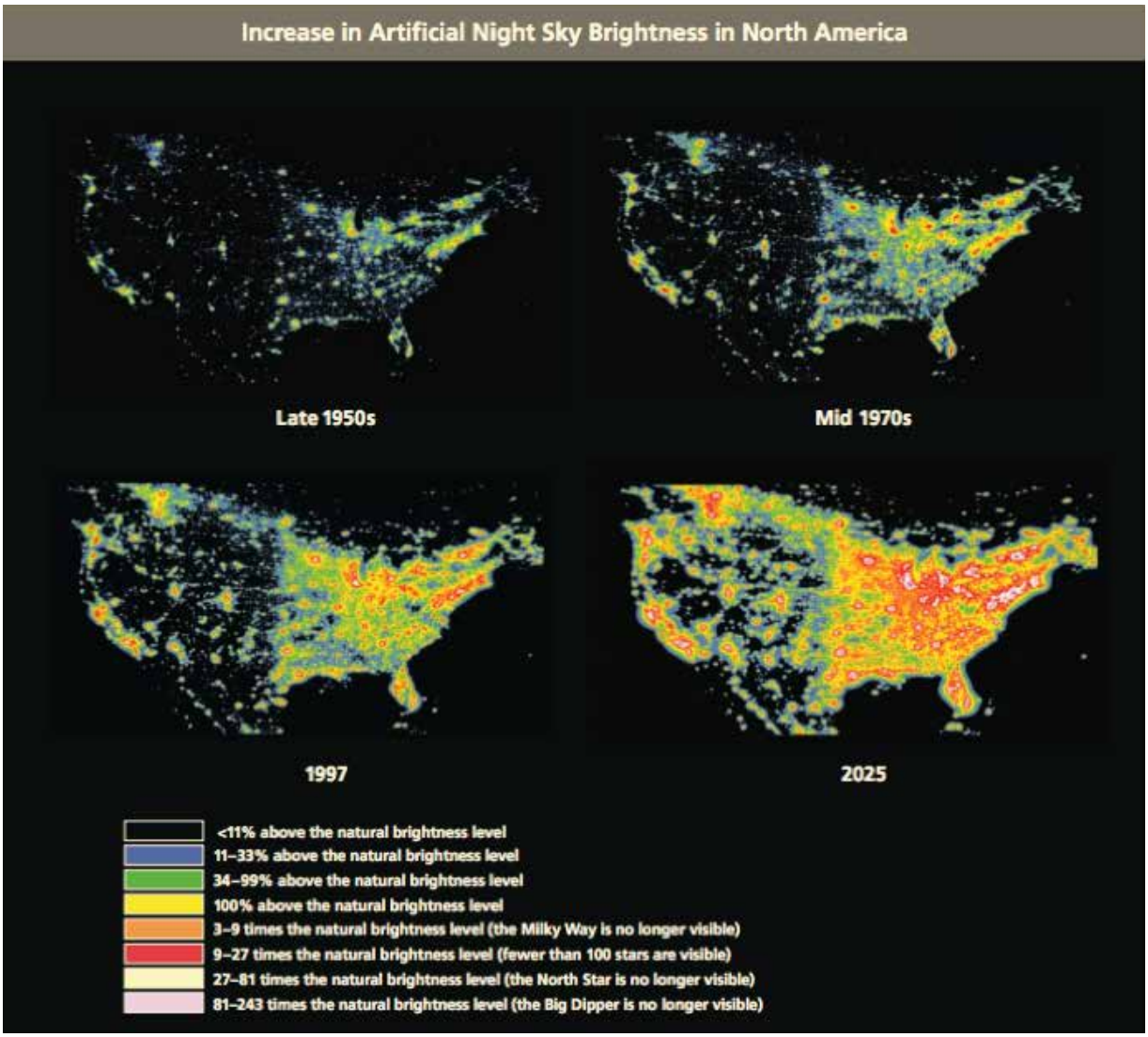


Figure 4: Historic and projected artificial night sky brightness [8]

challenging to maximize low light (scotopic) vision and minimize the effect on circadian rhythm as they are both sensitive to blue light.

From a safety perspective, glare from lighting interferes with scotopic vision, although the sleep delaying effect in drivers could be viewed as beneficial. A further discussion of methods to mitigate such light pollution, such as automatic switching, restricting illumination to a downward cone and reducing glare, can be found in the Lighting section of this report. Sensors to detect light pollution can be tightly coupled to the smart lighting systems themselves.

Noise pollution also has adverse effects on sleep cycles at night. An association between exposure to excessive road noise and coronary heart disease has also been demonstrated [12]. The Federal Highway Administration (FHWA) has published strategies for standard approaches to noise measurement and abatement, upon which FHWA approval and funding is contingent [13]. These include noise reduction factors for predicting human impact in the built environment. It should be noted that freight volume and speed in the LaGrange and West Point areas will be the key drivers of noise on The Ray. Furthermore, human perception of noise volume is not linear, hence a 50% reduction in noise energy may be barely perceptible.

A highly modular approach to noise sensing is the Sentec/Polysolar Solar Owl, which is a wireless solar-powered noise detector that can be mounted on street lamps [34].

As most of The Ray is in areas of low population density, the impact of light and noise pollution is far lower than an urban highway. In other parts of this report, we propose modifications of lighting and the road surface as well as the promotion of electric vehicles. We expect these measures to make significant reductions in light and noise pollution near LaGrange, West Point and sensitive wildlife areas. Evidence gathered from pollution monitoring will serve to justify continued investment in these measures, to ensure support from The Ray's local government partners and to recommend the best measures to state DOTs and the EPA.

FURTHER MONITORING TECHNOLOGY

Following the deployment of a pollution monitoring network and the necessary connectivity to achieve this, there are several options for extending the sensor network to further monitoring and data collection activities.

INFRASTRUCTURE MONITORING

Maintenance schedules for road infrastructure are typically set by highway authorities and depend on projected road wear, priority of the road as well as the availability and cost of capital equipment for completing the project. Infrastructure monitoring systems could serve to target maintenance more precisely to areas of need and improve predictive models by taking into consideration variations in road wear through changing traffic flows and weather patterns.

In 2014, US governments at all levels spent $165 billion on highway construction, operations and maintenance; the Federal Highway Administration alone has requested $53 billion for FY 2016 [14,15]. From 2008-2014, $65 billion of federal funds were transferred to cover the chronic shortfall in highway funding. With resistance to increased funding allocation for highways from general funds and opposition to increasing revenue from gas taxes, it is likely that further reductions in maintenance spending will occur to keep strategic funds solvent. This challenge is further exacerbated by the increase in road usage due to population growth and increase in the average age of roadways. The key benefit of monitoring may be to reduce overall spending on unnecessary interventions, or shift spending to low cost early interventions to save major repaving exercises.

Monitoring of bridges across the highway and across watercourses is a particular challenge with high profile bridge collapses bringing the issue to national attention. The American Road & Transportation Builders Association's analysis of the 2014 National Bridge Inventory shows over 61,000 bridges in the US are structurally deficient, whilst bearing 215 million daily crossings [20].

TECHNOLOGY ASSESSMENTS AND RECOMMENDATIONS

There are several strategies for infrastructure monitoring. A few examples include:

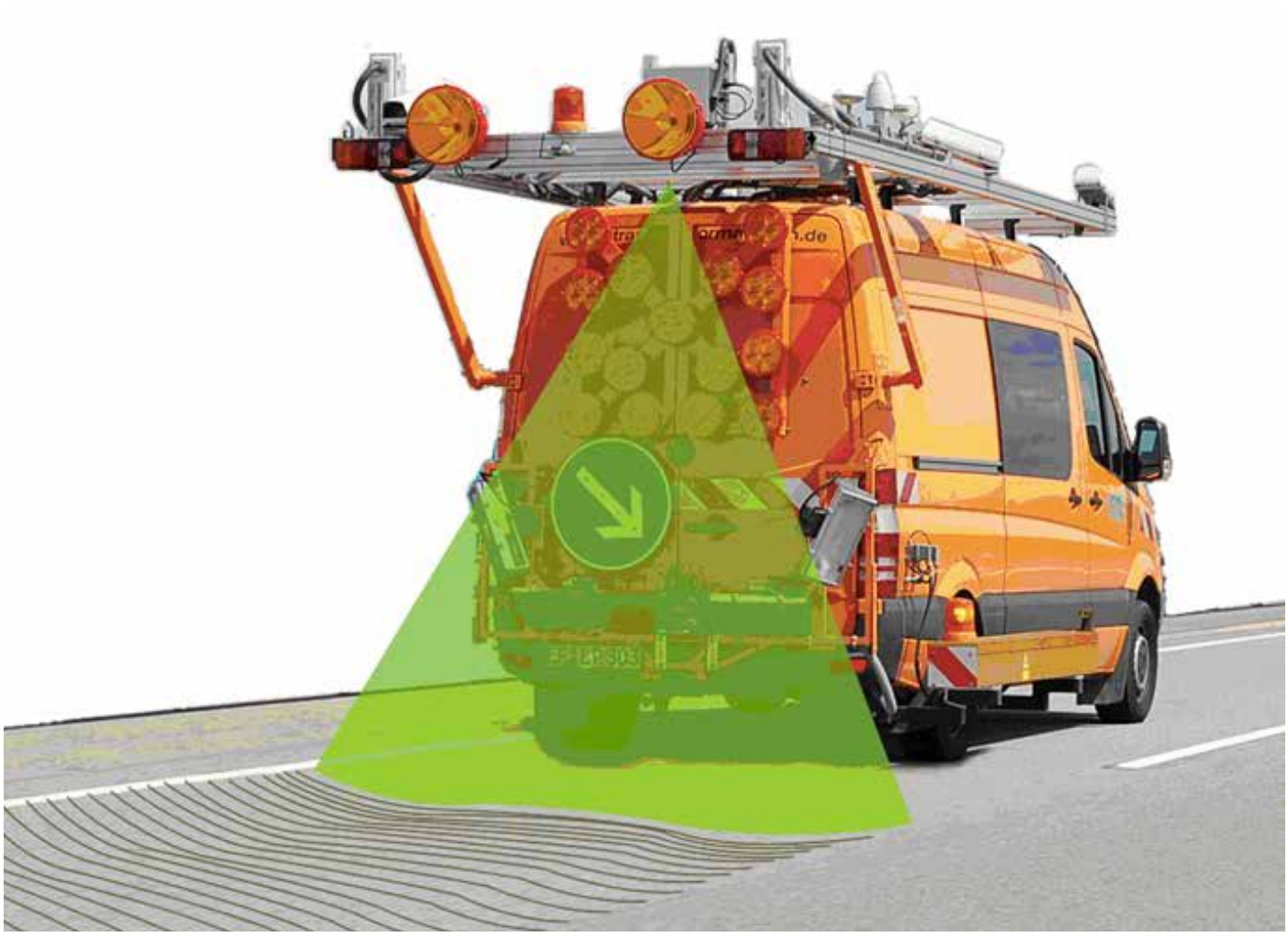
• Enabling status reporting into connected infrastructure added to The Ray, including lighting, solar panels and billboards, allowing for targeted repairs on infrastructure and development of predictive models for instrumentation failure.

• Strain gauges and fiber optic monitoring, such as used by Lifespan Technologies and Omnisens, can detect deformations in bridges and other structures, and has been trialed by South Carolina DOT [22,23]. These technologies scale well with structure length, so may be suitable for detecting damage in crash barriers.

• LiDAR (light detection and ranging) is a laser scanning technology that is now highly mobile. The Frauenhofer Institute has demonstrated a van-mounted prototype that can permit road profile scans at highway speeds [21].

• Acoustic and vibration monitoring for assessing subsurface structural health, such as the online monitoring systems provided by Physical Acoustics [24].

• Crowdsourced reporting of road damage. This has been best achieved in urban communities with the strongest sense of local ownership over the roadway. Potential partner or model platforms include SeeClickFix in the US, Fill That Hole and Fix My Street in the UK [17,18,19].



MONITORING FOR SAFETY

There is a wide range of strategies for promoting safer driving. The National Motor Vehicle Crash Causation Survey attributes the reason for the critical pre-crash event to the driver in 94% of crashes. Clearly, autonomous vehicles offer an excellent route to dramatically reducing this figure, but there are immediate interventions that may offer significant benefits.

Changes in driver behavior may be achieved directly through highlighting unsafe behavior or promoting safe behavior. Indirect approaches include providing anonymized data to identify key challenges to planning authorities and actively supporting the enforcement of regulations.

Table 1. Driver-, Vehicle-, and Environment-Related Critical Reasons

Critical Reason Attributed to	Estimated	
	Number	Percentage* ± 95% conf. limits
Drivers	2,046,000	94% ±2.2%
Vehicles	44,000	2% ±0.7%
Environment	52,000	2% ±1.3%
Unknown Critical Reasons	47,000	2% ±1.4%
Total	2,189,000	100%

*Percentages are based on unrounded estimated frequencies
(Data Source: NMVCCS 2005–2007)

Examples of monitoring technologies include:

• Spot and average speed cameras near built up areas

• CCTV monitoring of incidents and dangerous driving. When coupled with machine vision technology, this technology may become fully automated

• Microphones combined with machine learning for automated crash notification and early warning for emergency services, as demonstrated by Audio Analytic [26]

• High speed weigh-in-motion technologies to detect overweight freight vehicles, such as the imaging-based system developed by Camea and the piezoelectric sensor system developed by Mettler Toledo [28,29]

• Mobile seatbelt compliance sensors based on novel image processing technology are being trialed in Finland [30]

The impact of historic changes in driver behavior is best illustrated through the promotion of seatbelt use. Compliance was at 11% in 1981 and reached 85% in 2010, with an estimated 13,000 lives saved annually as a result [31]. A further 4,000 lives may be saved each year if compliance was at 100%.

DATA FOR VALUE-ADDED SERVICES

A range of data underpins the above monitoring strategies and these may also serve to add additional value for road users and other stakeholders. The following three examples illustrate a small fraction of the possible strategies.

Traffic counts can help to assess carbon emissions more precisely. Combining this with open path FTIR, carbon emission factors from individual vehicle classes can be better modeled to further refine emissions estimates. As vehicles increasingly monitor their own emissions, The Ray could offer a service to combine vehicle-reported data with road sensor data. It should be noted that GDOT has an initial traffic counting system in place including stations on The Ray [32].

Automatic number plate recognition (ANPR) is an enabling technology for some speed cameras and can help to enrich traffic count data and allow for toll enforcement independently of RFID transponders. It should be noted that whilst tolls offer an alternative source of revenue to fund The Ray, they can be a highly regressive form of road taxation. ANPR may allow for underprivileged groups to have discounted access, whilst also providing free access to drivers of environmentally friendly vehicles. LiDAR scanning can offer general mapping benefits for advanced geolocation enabled services. These maps can help to provide training and navigation data for self-driving cars, and also offer benefits as a reference scan for accident forensics.

IMPLEMENTATION

INFRASTRUCTURE

The first considerations of any sensor implementation are the geographic scope, spatial and temporal resolution of the sensors and the sensitivity necessary for detection (impacted, for example, by signal-to-background ratio). For initial pollution monitoring, a series of diffusion tubes and microphones may suffice producing monthly estimates of air pollution and noise levels at extremely low cost (with unit costs of the order of tens of dollars). Ultimately, The Ray can serve to demonstrate the added benefits of higher resolution monitoring for which a flexible, robust sensor network is needed.

The emergence of the Internet of Things, where a large number of devices are capable of communicating with each other directly, offers the possibility of such a low cost, flexible network. The basic format consists of a sensor combined with a low-powered ARM-based chip with several connectivity and power options. Local processing of point data using these low-powered chips and application-specific ICs can be combined with cloud-based processing of data sets, eliminating the need for dedicated analysis tools and processing power.

Wired sensors may be suitable for reliable secure connections, where traffic management and safety are a concern. If periodic interruptions in connections or fluctuations in bandwidth are acceptable, several options for wireless networking exist. For widely spaced sensors in rural areas, direct connection to 3G/4G networks may be necessary, essentially acting as a remote sensor. Alternatively, a single wired or 4G sensor hub may be coupled using local radio-frequency networking protocols such as Zigbee, Bluetooth Low Energy and Thread. A review of connectivity platforms is here [35]. Key considerations include bandwidth requirements, latency and the need for self-healing, modular networks. A self-healing mesh network approach enables movable sensor networks (as described in the Solar Owl example) that can be reconfigured based on need and that are robust to the loss of any individual sensor unit.

In general, solar power offers the most robust option for sensors at all scales, although power harvesting technology has been demonstrated on infrastructure projects, particularly for powering low powered microelectromechanical systems (MEMS).

In addition to movable modular sensors, mobile sensors can be mounted to service vehicles, or potentially freight vehicles traversing the corridor. The growth of autonomous vehicles will continue to increase the density of sensor platforms on the road, reducing the need for fixed sensors. Drones and satellite-based remote sensing may be applicable in very low-density off-grid corridors in other parts of the country.

DATA OUTPUTS AND AUDIENCES

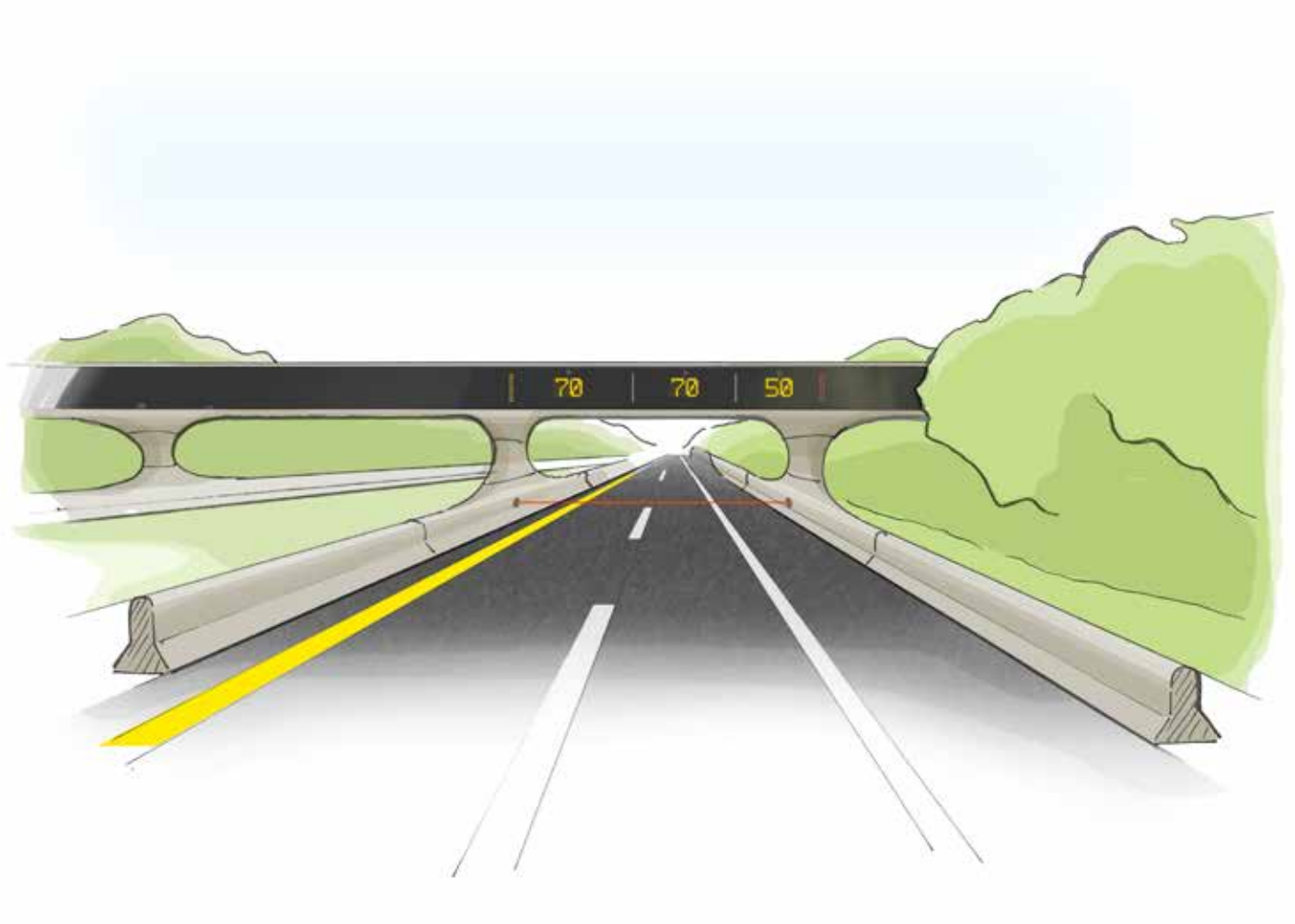
There are several key audiences and outputs for data processed:

- Decision makers – The Ray, GDOT, corporate partners, federal highways agency. Measuring whether a pollution or safety intervention has worked and how cost effective it is

- Road users – real time data on pollution and safety, alongside awareness data on their personal environmental impact and routes to mitigate it. This audience could be reached through smart billboards, dashboard and mobile apps, and at the visitors center

- Emergency services – rapid accident reporting and predictive information in the longer term

- Maintenance contractors – targeted road and sensor status reports for optimizing work schedules



• Traffic managers – supporting traffic management around road works and accidents (due to the low level of congestion on rural highways, most sophisticated traffic management innovation is likely to come from cities)

• Local employers and commuters – support and data for planning ridesharing or carpooling along shared commuter corridor

• Citizens – improved awareness of technologies piloted on The Ray through social media and mobile integration

RECOMMENDATIONS FOR THE RAY

The ideal long-term approach is for The Ray to create an open platform for sharing data, combining the EPA's minimum standards for monitoring with the robustness needed to handle the range of data types and sources discussed. Although ultimately this data may have marketable value to support the road, an open data strategy has typically been necessary for public-interest projects to build up a user community to critical mass. A major condition of this is that individual data points can be sufficiently anonymized.

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[25]http://www-nrd.nhtsa.dot.gov/pubs/812115.pdf
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[27]http://www.cs.dartmouth.edu/~campbell/carsafe.pdf
[28]http://www.camea.cz/en/traffic-applications/weigh-in-motion/
[29]http://us.mt.com/us/en/home/products/Transport_and_Logistics_Solutions/Truck_Scales/WIM.html
[30]http://www.itsinternational.com/categories/enforcement/features/automating-seat-belt-compliance-a-priority-for-road-safety/
[31]http://www.cdc.gov/motorvehiclesafety/seatbeltbrief/

[32]http://geocounts.com/gdot/
[33]http://www.libelium.com/smart-water-sensors-monitor-water-quality-leakages-wastes-in-rivers-lakes-sea/
[34]http://www.sentec.co.uk/news-and-events/news-archive/keeping-the-noise-down
[35]http://www.rs-online.com/designspark/electronics/eng/knowledge-item/eleven-internet-of-things-iot-protocols-you-need-to-know-about
[36]http://www.et.co.uk/docs/RSD5000_Remote%20Sensing%20Device%20Product%20Datasheet.pdf
[37]http://www.kassay.com/kassayfsi_airport_and_transportation.shtml
[38]http://portal.uc3m.es/portal/page/portal/actualidad_cientifica/noticias/analyze_pollution
[39]http://aircarecolorado.com/rapidscreen/
[40]http://www.der.wa.gov.au/our-work/programs/204-cleanrun-roadside-emissions-monitoring

ATMOSPHERIC CARBON CAPTURE

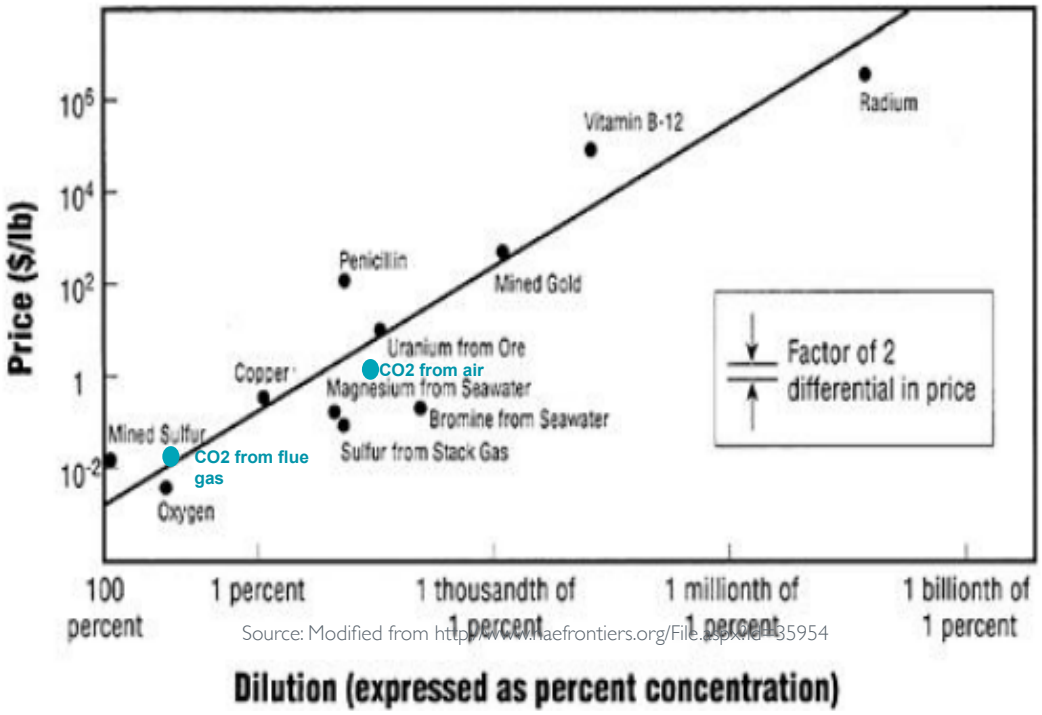
- It is technically possible to capture CO2 from the atmosphere
- However as the atmospheric CO2 concentration is very low (~400ppm) the process uses a lot of energy (>6GJ/ton) and is very expensive (~$150-500/ton). For comparison the cost of capturing CO2 from a power station flue is $40/ton and uses ~3.6GJ/ton of energy
- There is no benefit in situating the process next to a highway – the CO2 concentration will not be sufficiently higher to offset the higher deployment costs compared to desert land
- If once the world has radically reduced carbon emissions, the climate is still warming, atmospheric carbon capture may be useful as a final attempt to secure the planet's survival. It is right that academics are exploring options for this scenario as a long-term geoengineering strategy
- However until that time it is better to invest in scaling up technologies to reduce carbon emissions (e.g. solar power) and biological routes to carbon sequestration (e.g. reforestation)

CO2 emissions into the atmosphere are a major cause of climate change and technologies are being developed to capture CO2, and to store or use it. Most technologies have been developed for large point sources of CO2 like coal-fired power plants or cement works, and these aim to capture 90% of the CO2 in the flue gas stream [1]. The concentration of CO2 in the flue gas stream is typically about 12% for power plants.

Some technologies are also being developed for the much more challenging purpose of capturing CO2 from the atmosphere at the much lower concentrations of about 400ppm (0.04%). The laws of thermodynamics mean that these processes require a large amount of energy, and they typically only capture a few % (at most) of the CO2 in the air.

CO2 capture involves contacting the CO2 containing gas with a liquid (e.g. an amine), or a solid (e.g. activated carbon) that binds the CO2 via a chemical or physical bond. The CO2 rich solvent is then heated or put through a low-pressure environment to release pure CO2 that can be stored or converted to other chemicals. The solvent can then be reused to capture more CO2 [2].

The lower the concentration of CO2 in the gas entering the capture equipment the more expensive it is in terms of both energy and dollars to capture the CO2. This is true of extracting any material – the more dilute it is in the source material, the more costly it is to extract.



Source: Modified from http://www.nae.edu/File.aspx?id=35954

In the air around a major highway, there is about 300 times less CO2 than in a power plant smoke stack. Unless the CO2 capture plant is very close to the side of the road (within 30m) the CO2 concentration is unlikely to be much higher than ambient [3].

This means that capturing the CO2 from ambient air is much more difficult and expensive per ton of CO2. It requires >6GJ/ton (1,667 kWh/ton) to capture ambient CO2. That is equivalent to burning 16 tons of coal to capture 1 kg CO2 so the energy to run the process must come from renewables and not from the grid, or more CO2 will be emitted than is captured. Estimated costs are $150-$500 per ton depending on the capture method used [4].

There are two main companies pursuing CO2 capture from ambient air, Carbon Engineering [5] and Global Thermostat [6].

Carbon Engineering uses very large-scale units containing sodium hydroxide. A trial in Canada appears to have ended in 2012 and no further progress has been published [7]. Sodium hydroxide is corrosive and would require large stainless steel tanks. Vapor containment would also be important. The efficacy of this system is not proven, and there are likely to be safety concerns associated with co-locating it with the highway. Innovia does not recommend pursuing this.

Global Thermostat uses large ceramic blocks with an amine bonded to the surface. These units are smaller and can be regenerated at a lower temperature using steam. [8]. They have a self-funded trial unit at SRI after failing to secure DOE funding because of the high cost of the technique [9]. Innovia spoke to the founder, Professor Peter Eisenberg. He is interested in working with the Foundation to demonstrate his technology. However, in order to be commercially viable, the technology needs a source of waste heat that it can use to create low grade steam for regeneration (at 70-80°C [10].

Source: http://www.technologyreview.com/featuredstory/531346/can-sucking-co2-out-of-the-atmosphere-really-work/

Global Thermostat currently suggests co-locating their technology with an industrial process that produces waste heat, and that has a use for the collected CO2. Otherwise, the costs for producing the steam and for storing or transporting the CO2 would make the process even more expensive. With a current estimated cost of $50-$150 per ton CO2 captured, the process is only likely to be economically viable if the CO2 produced can be upcycled into a more valuable end product (e.g. formic acid and polymer precursor derivatives) and the heat to drive the process is free. Even in these circumstances, a carbon tax may be needed to drive wide scale adoption.

RECOMMENDATIONS FOR THE RAY

It could be argued that in the long-term, if we truly wish to combat climate change, then simply ceasing to emit CO2 will not be enough. The CO2 that has been emitted into the atmosphere over the course of the industrial revolution will stay there for a very long time, as natural methods of sequestration in the carbon cycle operate over decades and centuries. If we do reach the point where it is necessary to capture carbon from the atmosphere, this technology may well be one of the more viable and economic options. However, it is unclear whether this is a likely scenario.

As atmospheric carbon capture can happen at any location, it may never be economical to locate it by the roadside.

Innovia does not recommend atmospheric carbon capture technology on The Ray.

Algae and plants are also used for atmospheric CO2 capture and biological fixation. This is covered in other sections of the report.

1.http://www.technologyreview.com/featuredstory/531346/can-sucking-co2-out-of-the-atmosphere-really-work/
2.Yu, Cheng-Hsiu, Chih-Hung Huang, and Chung-Sung Tan. "A review of CO2 capture by absorption and adsorption." Aerosol and Air Quality Research 12.5 (2012): 745-769.
3.Durant, J. L., et al. "Short-term variation in near-highway air pollutant gradients on a winter morning." Atmospheric chemistry and physics (Print) 10.2 (2010): 5599.
4.House, Kurt Zenz, et al. "Economic and energetic analysis of capturing CO2 from ambient air." Proceedings of the National Academy of Sciences 108.51 (2011): 20428-20433.
5.http://carbonengineering.com/
6.http://globalthermostat.com/what-we-do/about-carbon-capture-and-use/
7.http://fortune.com/2011/10/07/the-business-of-cooling-the-planet/
8.http://www.naefrontiers.org/File.aspx?id=35954
9.http://www.marcgunther.com/a-global-thermostat/

BIOFUELS

- Whilst first generation biofuels are well proven and second generation biofuels have emerged, the environmental impacts of these technologies due to land use change and impact on food crops make them of limited use in large-scale ethical manufacturing of fuel
- Third generation algal biofuels represent a possible step change in performance, but remain relatively unproven at a large scale
- Deployment of the algal fuel technology is optimized for brownfield sites and factory scale production, rather than the narrow right-of-way
- Development of algal fuel technology is a matter of efficient process engineering, genetic engineering and strain selection. These are not activities where a demonstrator on The Ray will have significant impact
- Solar photovoltaic is projected to provide a higher power density than algal fuels for the foreseeable future, hence supporting the transition to electric vehicles should be a priority for The Ray

Biofuels have been variously presented as the key to affordable clean energy and as a major threat to food security. There are in fact a wide range of strategies for producing renewable biofuels that are typically divided into three generations:

• **First generation biofuels** – Produced through fermentation of sugars, first-generation bioethanol derives from carbohydrates in food crops, such as corn. Oil crops also fall into this category.

• **Second generation biofuels** – Produced through thermal and enzymatic treatment of lignocellulosic materials, second generation biofuels are produced from grasses, wood and agricultural wastes. Municipal, forestry and horticultural wastes are also processed through this route.

• **Third generation biofuels** – Primarily derived from microalgae, third-generation fuels do not require to be sourced from arable land. The potential for efficient bioprocessing and genetic engineering could result in the most efficient production process when this technology matures.

FIRST GENERATION BIOFUELS

First-generation fuels dominate the current global landscape. The US is the largest biofuels producer, with the vast majority derived from corn, particularly in the Midwest Corn Belt. About half of US corn production now goes to ethanol manufacture, representing about 10% of gasoline.

Following four decades of investment in sugarcane-derived ethanol, Brazil is the world's largest bioethanol exporter, with gasoline-powered vehicles typically operating on 20-25% ethanol [1]. These investments were driven primarily by energy security concerns, following the 1973 oil crisis, rather than environmentalism.

As major food exporters, both Brazilian and US arable land are key to keeping down global food prices. With the increase in global population and living standards as well as the impact of climate change on agriculture (particularly droughts of increasing severity), it is unwise to further transfer food crops to fuel or clear forest land that acts as a carbon sink. Notably, the hardest hit communities are in the poorest nations, whilst the end-users of biofuel ultimately driving demand are among the most insulated from food price rises [2].

Most biodiesel is currently derived from oil crops (soy bean and palm oils in particular). Diversion of over 10% of oil crop production to fuel has raised cooking oil prices and driven further deforestation, particularly in Southeast Asia.

SECOND-GENERATION BIOFUELS

Second-generation biofuels are still an emerging technology making use of byproducts ranging from municipal solid waste to agricultural wastes such as wheat straw.

Switchgrass, which may be incorporated into a bioswale alongside the The Ray, is an efficient source of cellulosic fuel. However harvest frequencies would have to be limited to a single annual harvest, in order to guarantee a deep root structure for soil carbon fixation, water filtration and ecosystem development.

Conversion of cellulosic ethanol requires pretreatment with cellulase enzymes, which are themselves a product of bioprocessing, in order to release sugars for fermentation. Companies like Iogen (Ottawa, ON) are pioneering in this field. Whilst cellulase prices have been falling, this additional step makes for expensive and inefficient fuel production.

THIRD-GENERATION ALGAL BIOFUELS

The term alga is not consistently defined, but broadly encompasses a range of organisms capable of fixing carbon through photosynthesis (i.e. phototrophs). For example, macroalgae include the brown alga genus *Sargassum* in the kelp order and red alga genus *Gracillaria*, whilst microalgae include both higher organisms (eukaryotes), such as *Chlorella*, and lower organisms (prokaryotes), such as blue-green alga *Arthrospira*. The two principal approaches to algal biofuels are harvesting kelps and macroalgae from the ocean, and the controlled growth of microalgae in contained reactors or pools. For inland Georgia, only the latter strategy is suitable.

Algae can be bred and engineered to yield a wide range of products. High volume products include biofuel (particularly from engineered cyanobacteria), fertilizer, and agricultural or aquaculture feed (often Spirulina). However, the economics of processing algae on a large scale can limit their ability to compete with high volume products from other sources.

Traditionally, high performance bioprocessing has been used for higher value products. These include food (agar desserts), dietary supplements (Spirulina), research products (agar plates). Algae are seen as an emerging source of new drugs and an alternative workhorse for biopharmaceuticals. All of these applications permit higher processing costs for biofuels.

Optimization of cyanobacteria for improved biofuel yields is taking place in laboratories across the world using three key strategies. Firstly, there is high-throughput screening of strains harvested from oceans worldwide. Secondly, current methods in molecular biology (such as directed evolution) are used to genetically engineer known strains using novel genetic material. Finally, a new approach is synthetic biology, the engineering of entirely new organisms from scratch, using genetic components from a wide variety of organisms. This is a field in its infancy but promises to radically reduce the energy expended during the growth phase of the organism and therefore overall production costs.

Although the cost is falling, due to these efforts, algal biodiesel production typically exceed $200/bbl. In 2014, the Department of Energy launched a $25m funding program alongside a target of $5 per gallon gasoline equivalent ($160 /bbl biodiesel) [3]. The economics of small-scale biodiesel can be cost competitive with gasoline if it is a byproduct of wastewater treatment, although the nature of waste stream contaminants may require significant pre-treatment [4].

The figures below show some examples of pioneers in this field based in North America, using different formats for algal farming and taking differing approaches to sourcing and developing algae. Sapphire Energy uses an open pool system, Solix uses panels and surface reactors and Joule Unlimited is seeking to combine synthetic biology and flue gas carbon dioxide with continuous manufacturing in a closed photobioreactor [1,2,3]. The only one of these formats suitable for a roadway deployment is Joule's reactor and the requirement for a supply of freshwater is a significant challenge. In general, most algal fuel companies that have survived through their early stages have shifted towards high value products and away from commodity products such as fuel.

Figure 1: Solix

Figure 2: Sapphire Energy

Figure 3: Joule Unlimited

COMPARISON OF BIOFUEL SOURCES

One approach to choosing the best technology is a comparison of the potential power density (average power output per unit land) that each offers assuming an average solar irradiance of 208 W/m^2 over the course of the year in this part of Georgia.

It should be noted that the conversion efficiency of biomass to liquid fuels and energy efficiency of the vehicles has not been accounted for in the table below. This is significantly lower than the corresponding transmission efficiency and in-battery losses that occur upon conversion of photovoltaic energy to kinetic energy in an electric vehicle (approx. 68% efficient).

Algal fuel efficiency is in part limited compared to photovoltaic by the nature of light harvesting in biological systems, where a significant part of the energy of the light spectrum is discarded. The biological system is optimized for robustness and creation of molecular complexity rather than production of a single industrial product.

ENERGY SOURCE	POWER DENSITY (W / m^2)
Photovoltaic (polycrystalline Si, 12% efficiency)	25
Sugarcane (best first-gen fuel)	0.4
Switchgrass from bioswales (one annual harvest)	0.7
Possible upper limit on algal fuels	10

BIOFUEL PROCESSING AND USAGE

Bioethanol is produced by fermentation of carbohydrates derived principally from corn and sugar cane. A key challenge in making this process efficient is that ethanol-water mixtures are azeotropic solutions, which means that they are separated less readily by energy-intensive distillation processes. Bioethanol is included at low percentages (under 25%) in regular gasoline mixes and this represents the vast majority of bioethanol use in the US and Brazil. The E-85 standard, with an upper limit of 85% ethanol can only be used by flex fuel vehicles due to the need for sensors to account for variations in ethanol vapor pressure to prevent premature ignition or cold start problems. The US fleet of alternative fuel vehicles adapted for E85 is steadily growing and is now approaching 900,000 [8].

Biodiesel is produced by three main processes:

• Transesterification of fatty acids derived from vegetable oils or animal fats (or derived from algal sources) yields fatty acid methyl esters.

• Hydrotreating of vegetable oils and fats yields paraffins.

• Biomass-to-Liquids is achieved through biogas production, followed by shift reaction to yield carbon monoxide, and completed by the Fischer-Tropsch process to produce long chain hydrocarbons suitable for biodiesel.

The latter technology is in its infancy, and is relatively uncompetitive with other processes. Germany leads adoption of biodiesel with the EU representing both the largest producer and largest importer [1]. Manufacturer acceptance has been slow, with several companies advising customers to use B-5 (5% biodiesel) at most.

The I-75 Green Corridor Project has placed 30 E-85 stations and 10 B-20 stations allowing for continuous access to biofuels across the I-75, including in Georgia [9].

RECOMMENDATIONS FOR THE RAY

Innovia does not recommend significant investment in biofuels for the The Ray.

The impacts of first-generation fuels in Brazil, the US and Indonesia has been particularly detrimental to the environment and food price inflation worldwide, hence promoting its development is against the mission statement of The Ray.

Second generation fuels may be used opportunistically, but primarily as a waste mitigation measure. The most straightforward approach would be to engage with the I-75 Project and make an environmental impact assessment of the fuel they supply, as it may be a mix of food crops and waste.

Third generation biofuels are being developed by researchers with biological and bioprocessing expertise; coupling this development to a road innovation program like The Ray offers little benefit to either party. Investing in solar photovoltaics is a better use of land and investment.

If a corporate partner has an existing hybrid fleet that they wish to power and further land outside of the corridor is available, this technology could be revisited in partnership with a water treatment facility and an algal fuel manufacturer.

[1]UNCTAD. (2014). The State of the Biofuels Market : regulatory, trade and development perspectives, 84–88.
[2]Wise, T., & Brill, M. (2012). Fueling the Food Crisis : The Cost to Developing Countries of US Corn Ethanol Expansion October 2012, (October), 32.
[3]http://energy.gov/eere/articles/energy-department-announces-25-million-reduce-costs-algal-biofuels
[4]Lundquist, T. J., Woertz, I. C., Quinn, N. W. T., & Benemann, J. R. (2010). A Realistic Technology and Engineering Assessment of Algae Biofuel Production. Energy
[5]http://www.sapphireenergy.com/
[6]http://www.solixbiosystems.com/
[7]www.jouleunlimited.com
[8]http://www.afdc.energy.gov/data/10300
[9]http://www.cleanfuelscorridor.com

BIOGAS FROM ANAEROBIC DIGESTION

- Anaerobic digestion of waste biomass to produce biogas can alleviate a waste stream, deliver renewable energy, and reduce climate change
- This biogas can be used to generate electricity or power vehicles
- Biogas will be a part of the renewable energy future. It could make a worthwhile contribution to transportation energy, but its potential is limited, and it will be never be able to provide a large fraction of the world's transportation energy

Many forms of 'soft' biological waste can be anaerobically digested to produce biogas, a mixture of methane and CO2. In the absence of oxygen bacteria break down the biomass to produce methane. The typical sources of waste biomass are [1]:

- landfill sites;
- manure from cows, hogs or chickens;
- waste water;
- industrial, institutional and commercial organic waste; and
- food waste.

This biogas can be use to generate electricity in generators, or to power vehicles. Compressed gas bus fleets are popular in many countries.

Anaerobic digestion of waste biomass has several benefits. It both alleviates the impact of a waste stream and generates renewable energy. If it is replacing a natural decomposition process that would release methane into the atmosphere, it can hugely reduce the overall carbon footprint, as methane is a much more powerful greenhouse gas than CO2.

However the overall potential of biogas from the aerobic digestion of biological waste is limited by the magnitude of these waste streams. In the US, the estimated annual technical potential (ignoring economic factors) of all biopower is 400 TWh/year, of which gaseous biomass contributes 88 TWh [1]. This compares with 818 TWh for rooftop solar PV, and 280,613 TWh for rural utility scale solar PV [1]. The US uses about 8000 TWh/year of energy for transportation [2]. So biogas can make a sizeable contribution to transportation, but will never deliver zero impact transportation on its own.

Another downside is that although natural gas has a high energy density per unit weight, it is low per unit volume. This means that vehicles need large and expensive fuel tanks to allow an acceptable range. One solution to this is liquified natural gas (LNG) vehicles, in which the fuel is stored at cryogenic temperatures. These are at an early stage of development and the infrastructure is quite expensive. UPS is trialling LNG vehicles in the US.

Solid biomass is a little different. It is typically high in cellulose and or lignin. These molecules are difficult to break down, and this requires a complex and usually inefficient enzymatic process. This is usually known as second generation biofuels, and can produce liquid fuels. The main sources of material are crop residues, forest residues, primary mill residues, secondary mill residues and urban wood waste.

[1] http://www.nrel.gov/docs/fy12osti/51946.pdf
[2] https://en.wikipedia.org/wiki/Energy_in_the_United_States#/media/File:LLNLUSEnergy2012.png

ELECTRIC VEHICLE CHARGING LANE

- All of the component technologies for a wireless electric vehicle charging lane have been demonstrated
- However the costs of installing a system on a major public highway are unclear (and likely to be high). Highways England is about to carry out an off-road trial to better assess this cost and a wide range of other factors
- If the range and charge-time of electric vehicles improves significantly then electric vehicle charging lanes may become unnecessary
- We don't expect an on-road trial of an electric vehicle charging lane to happen on The Ray immediately, but it is feasible within a few years
- We recommend watching closely for the results of Highways England's off-road trials and initiating early discussions with potential technology providers and commercial fleet owners whose vehicles use the I-85

Electric cars are growing in popularity but their range is currently quite limited. One possible solution is to charge the vehicles on the move with inductive coils embedded in the road, a process known as dynamic electric vehicle charging (DEVC). This involves significant expense in reinforcing the local electricity grid and in installing the coils in the road. Vehicles also need a receiver to use the system – one study estimated the manufacturing cost of this as $250 [6].

Wireless inductive charging of vehicles has evolved through various system options:

WIRELESS CHARGING OF STATIC VEHICLES

This is the simplest form of inductive vehicle charging technology. Charging stations could be made available to the public, perhaps in public car parking spaces, or owned by private or fleet owners of plug-in vehicles. This has the advantage of convenience, but will always have an efficiency loss compared with plugging the vehicle in. Current static inductive charging systems are around 90% efficient (Qualcomm claim >90% for their Halo system [7]).

RAPID CHARGING OF BUSES AT BUS STOPS

A number of cities have demonstrated rapid inductive charging of electric buses as they stop to pick up passengers, or during short breaks in their timetable. This provides top-up charging to keep the bus going during the day and the buses are fully charged overnight. [1,2]

Source: www.eltis.org/discover/case-studies/field-test-inductive-electric-bus-charging-netherlands

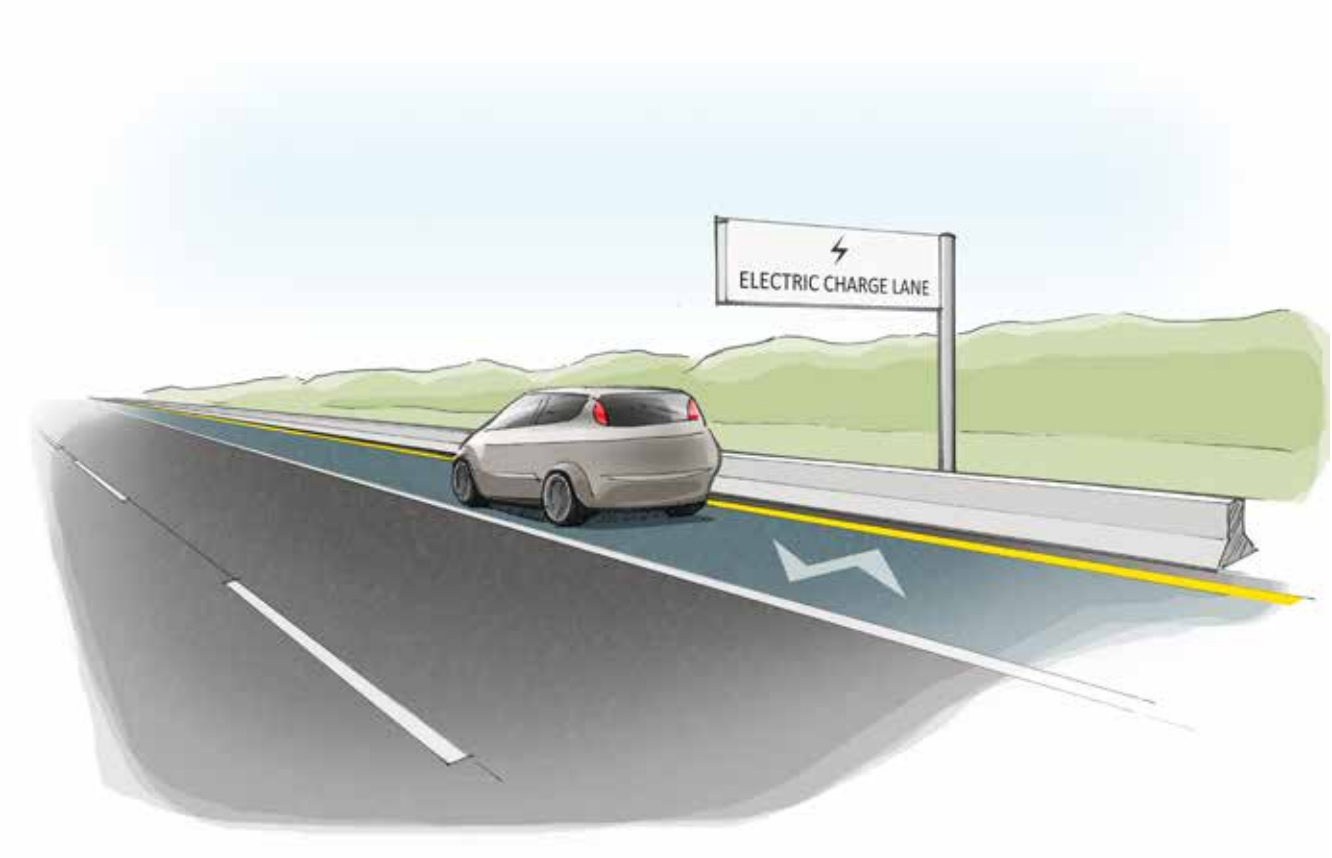
DYNAMIC CHARGING OF BUSES ALONG BUS ROUTES

This has been demonstrated in Gumi city in South Korea, where dynamic charging has been installed under the surface of an entire 7.5 mile bus route. [3] The project was carried out in partnership with Hyundai and Daewoo. Cost estimates by KAIST for the technology are $800,000 per lane per mile. An 83% grid-to-battery efficiency was achievable at an average power transfer rate of 100 kW, demonstrating a significant increase over previous trials [5]. A similar trial is underway in Park City, Utah [4].

Source: http://cities-today.com/south-korea-unveils-buses-which-charge-from-roads/

DYNAMIC CHARGING OF VEHICLES ON A PUBLIC HIGHWAY

This is a long-term vision is for public highways to have wireless charging lanes available for public use, with a suitable payment system that might raise revenue for the highways authority. Highways England published a feasibility study on powering electric vehicles on England's major roads in July 2015 [4]. They proposed an off-road trial of the technology in 2015, followed by an on-road trial in 2016/2017.



KEY PARTNERS

The landscape of technology providers in wireless power transfer is changing quickly. An emerging pattern is for a Tier 1 automotive supplier to partner with a smaller startup company. For example Delphi have partnered with WiTricity, and Yazaki have partnered with Evatran [6]. Qualcomm have also purchased technology from Auckland University in New Zealand, and are now marketing their Halo technology [7]. Highways England's feasibility study [4] includes an extensive list of technology providers on page 39-40.

Deployment of the technology will also require retrofitting existing electric and hybrid vehicles. In addition to manufacturing the coil and battery management system, retrofit costs estimated by KAIST to be $10-20,000 per heavy vehicle [5]. Key partners for this include UPS and Coca Cola who are pioneering the use of hybrid electric vehicle fleets [8,9].

RECOMMENDATIONS FOR THE RAY

Dynamic electric vehicle charging may be a technology that is ready to pilot on a public highway in a few years. We would recommend waiting for the results of Highways England's off-road trials, as this will be valuable for informing the technology selection for an on-road trial.

A first on-road trial is likely to involve a fleet of commercial hybrid or electric vehicles that drive the same route on a regular basis. This would be the easiest way to justify the expense of installing the trial system on a road. In addition, a vehicle retrofitted with a secondary coil may have a smaller battery capacity, resulting in reduced range outside of the DEVC lane, therefore a fixed route along the I-85 would limit range anxiety associated with private motor vehicles. If trial grid-to-battery efficiency translates to real world usage, dynamic charging of a hybrid vehicle could promote uptake of efficient electric drivetrains with lower weight batteries, offsetting the energy losses associated with wireless charging and decarbonizing transportation. The cost of the trial may be partly recouped through levying fees for early commercial adopters for whom DEVC offers additional value as a convenient method of range extension and faster, uninterrupted transit.

The final challenge is the cost and traffic disruption of installing the system on a busy interstate highway. If a new lane is added to the I-85 in a few years time, this might be the optimal time to trial the technology.

We do not expect an on-road trial of DEVC to happen on The Ray immediately, but it is feasible within the next few years. To kick start the project the Foundation could:

- Establish contact with potential technology providers (e.g. Delphi/WiTricity, Yazaki/Evatran, Kia/Hyundai, Qualcomm) to explore technology options and their interest in an on-road trial of DEVC
- Watch closely for the results of Highways England's trials in 2015/2016 (their reports so far have been informative and well written)
- Discuss with the corridor's main commercial residents the possibility of retrofitting electric or hybrid fleets with induction coils.
- If plans for a new lane in the I-85 progress, consider a DEVC trial as a matter of urgency

[1]http://www.eltis.org/discover/case-studies/field-test-inductive-electric-bus-charging-netherlands
[2]http://www.eltis.org/discover/case-studies/gruppo-torinese-trasporti-uses-electric-minibuses-turin-charged-within-7\
[3]http://www.bbc.co.uk/news/technology-23603751
[4]http://www.highways.gov.uk/knowledge/publications/1902/
[5]Innovia interview with Prof Chun T Rim, Wireless Energy Transfer, KAIST
[6]http://web.ornl.gov/adm/partnerships/events/Dec_Spark/Paulus_Wireless%20Power%20Transmission%20Presentation%20-%20Paulus%20v2.pdf
[7]https://www.qualcomm.com/products/halo/features
[8]Walkowicz (2012) NREL/T P-5400-53502 Coca-Cola Refreshments Class 8 Diesel Electric Hybrid Tractor Evaluation: 13-Month Final Report http://www.afdc.energy.gov/uploads/publication/coke_hybrid_tractor.pdf
[9]https://pressroom.ups.com/pressroom/ContentDetailsViewer.page?ConceptType=PressReleases&id=1441744963510-216

LOW CARBON CONCRETE

- A range of low carbon and carbon negative cement and concrete are proven at laboratory scale, offering improvements in material properties as well as environmental impact
- Several low carbon technologies are already on the market, having spent up to a decade receiving appropriate regulatory approval for use as structural material in public projects
- In general, the most mature technologies involve retrofit of existing Portland cement manufacturing plants using flue gas carbon dioxide generated at the site
- We do not expect a large-scale use of concrete in road construction on The Ray until I-85 is expanded. However, the expansion of the Georgia Visitor Information Center offers an immediate opportunity to use current generation technology and demonstrate it to the public
- We recommend building a broad consortium of providers to communicate the value of low carbon and carbon negative concrete to regulators and the public, with the goal of promoting a pro-innovation regulatory and investment environment in Georgia

Cement is responsible for 5% of the world's carbon emissions. Around 2bn tons are used every year, with each ton a source of 0.4 tons of CO2 as it is made [1]. Standard, or Portland, cement is made by calcining, heating limestone or clay to 1,500°C. This decomposes the limestone, producing large amounts of CO2. Carbon dioxide is also produced in providing energy to heat the process. Cement is a major component of concrete, and responsible for a large fraction of concrete's carbon footprint.

Life cycle analyses of roads estimate that over the course of 40 years of maintenance and operation over 80% of the road's carbon footprint still derives from construction, of which the majority is embodied carbon in construction materials [21]. It should be noted that these analyses exclude direct traffic emissions, which exceed construction emissions after only 2-3 years of operation. In addition, around 40 billion tonnes of aggregate materials (sand, gravel, limestone) are mined globally per annum with serious impact on land use, life safety, water and air pollution [22]. Local shortages of material have led to an increase in the average distance that aggregates are transported in the US, with a corresponding increase in carbon emissions and road wear.

Inorganic carbonates that can be used as building materials such as concrete and cement are a method of permanent CO2 sequestration due to their chemical composition [1,2]. This means that production of cements and concretes can be carbon neutral or even carbon negative. Innovia has evaluated a number of companies operating in this area.

Most of the companies producing these materials are small start-ups – some are still proving the technology and some have begun producing materials in small quantities. Whilst many of the materials produced have mechanical properties comparable to regular concrete and cement, their different chemistries and production methods may require regulatory approval before they can be used in construction [2].

Many of these materials have similar or better strength, hardness and toughness than traditional concrete. Use in construction applications is dependent on regulatory approval rather than material properties [3]. Obtaining regulatory approval for use in structural applications is a significant barrier in this conservative industry, as it is necessary to prove wear properties are as good as traditional construction materials.

Innovia estimates that the market has the long term potential to sequester 10-100 million tons of CO2 per year globally in a form where it is not rereleased to the atmosphere. As construction materials are a commodity product, reaching cost parity is critical for most large scale applications such as road building. The recent launch of the Carbon X-Prize shows the potential for broad engagement in generating valuable products from captured CO2 emissions [17].

KEY PARTNERS

Currently, there exists a range of technologies dedicated to reducing the carbon emissions of concrete production. The first generation of technologies can be broadly characterized as modifying the existing Portland cement process to modestly reduce CO2 emissions. As the final composition of cement is comparable to Portland cement and the process can use existing cement plants (with retrofitting), these technologies have the lowest regulatory hurdles and are close to cost parity already. The second generation of technologies involves changing cement chemistry at a fundamental level, with a knock-on impact on the concrete manufacturing process as well. These technologies are more challenging to implement and are still net carbon emitters. Finally, carbon negative concrete is in development that may ultimately turn The Ray itself into a carbon sink.

CARBON CURE

CarbonCure, based in Halifax, NS, manufactures Portland cement through a modified process. The reaction between cement, water and CO2 creates nanoparticles of calcium carbonate dispersed through the concrete and enhances mechanical properties. CO2 is used in both the mixing and curing stages [12]. CarbonCure's concrete is already used by 25 masonry producers in projects in North America and meets the ASTM C90 standard for load bearing concrete masonry units [13,15]. The

technology will be deployed at 40 more locations within the next 12 months including the Argos and Thomas Concrete plants in Atlanta, GA.

CarbonCure estimates that its carbonation process consumes 5% of the overall CO2 emissions of cement production without impacting weathering carbonation that is responsible for in on-site curing [15]. In addition, the strength benefits of the enhanced cement reduce the proportion of cement included in concrete manufacture, reducing overall CO2 emissions by 10%. Retrofit can be completed with minimal disruption within a week and, unlike many of the other technologies described, the output extends to ready-mix cement and not just pre-cast.

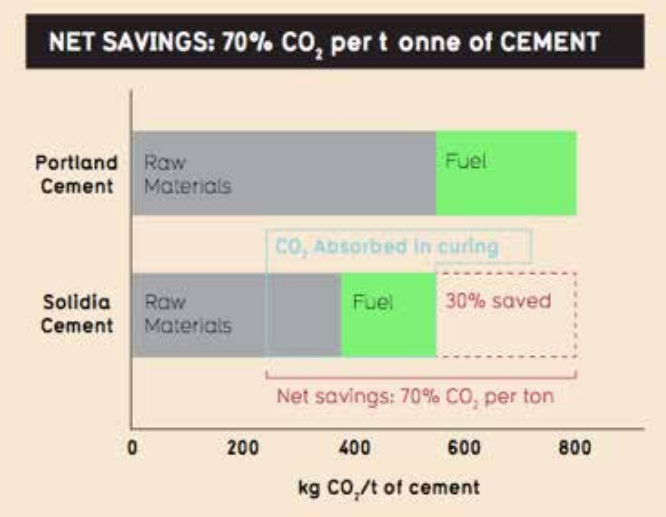
CALERA

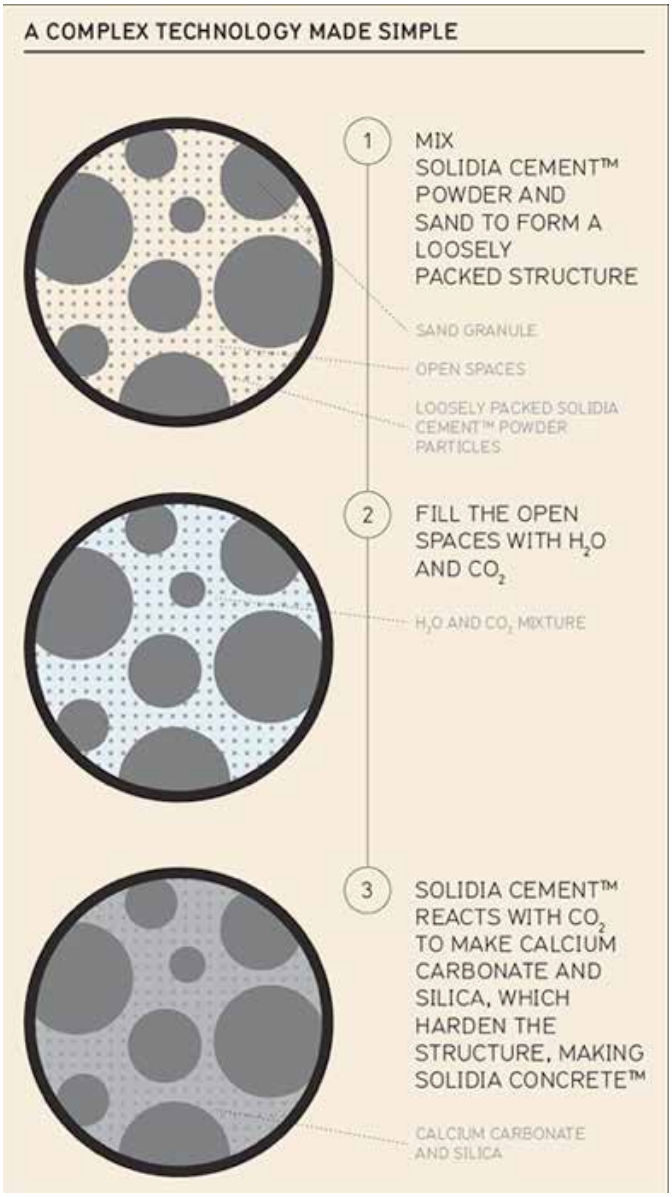
Calera is a US company with a pilot plant running for 2 years in California, which produces up to 2 tons of calcium carbonate to date, using waste CO2 produced by a coal power plant [9]. The process also reuses other waste streams such as waste water containing calcium.

CO2 is taken directly from the smoke stack of the power plant and converted into calcium carbonate in the form of vaterite. When water is added the vaterite recrystallizes to form aragonite, a strong and tough material found in the shells of marine life [10].

Capture of CO2 is achieved in an alkaline calcium solution. Regeneration of this solution requires an electrolysis of brines using significant input energy, which reduces the magnitude of overall CO2 mitigation [11]. The use of these brines also limits the locations where the process can be used. Due to the high impact of transporting aggregates over long distances, CO2 mitigation is further reduced by geographical constraints.

As the material is novel, Calera concrete is currently not approved for structural use and the company's focus is on decorative products.





SOLIDIA TECHNOLOGIES

Solidia Technologies has developed a novel method of solidifying (densifying) ceramic materials without using high temperature kilns. This novel technology is called gas-assisted reactive Hydrothermal Liquid Phase Densification. The process consists of four steps [4]:

1. A porous shaped compact with a network of interconnected pores is formed using conventional ceramic processing methods.

2. The porous compact is then infiltrated with a fluid composed of reactive cations and/or anions.

3. A hydrothermal reaction causes the part of the porous compact to dissolve and react with the fluid to form a product that reactively grows while filling the pore space.

4. CO2 is then injected into this solid to give an aluminum silicate microstructure [5,6].

This process modifies existing materials and equipment used in the cement industry, and has a 30% lower process temperature than traditional process, saving 70% of the CO2 per ton [7].

It sequesters 5% by weight CO2 and is structurally accredited to ASTM standard, claiming to be stronger than conventional Portland cement. It also requires less curing time and 60-100% of the water used in the process is recycled, resulting in a 30% energy saving. The company considerable support from the DOE and industrial partners, including Lafarge who are planning a large scale trial and have acquired equity in the company [8].

The process that Solidia have developed allows them to reduce the temperature of making cement by a factor of 4 [7]. It also uses the same raw materials as current cement making processes and can be done on existing industrial equipment. The additional materials the Solida process requires can come from a variety of sources including industrial waste products such as fly ash. Solidia has completed a trial in a cement plant in Whitehall, PA, where the process was run at a rate of 2000 tons per day and they measured an energy reduction of 30% and a concrete. Use in construction applications is dependent on regulatory approval rather than material properties [3]. Obtaining regulatory approval for use in structural applications is a significant barrier in this conservative industry, as it is necessary to prove wear properties are as good as traditional construction materials.

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reduction in CO2 emissions of 40% [16]. The cost is comparable to conventional Portland cement. There are also advantages for cement producers compared to current wet cement mixes, such as an ability to warehouse the material and reuse mixed cements – this could lead to increases in profit margin. A final benefit is a reduction in the water demand of up to 90%.

The DOT has signed a Cooperative Research and Development Agreement (CRADA) with Solidia to use their technologies. The technology and key claims have been independently verified by, among others, the Concrete Testing Laboratory in Illinois [8].

CARBON8

Carbon8 has its principal manufacturing location in Bristol, UK, and uses its Accelerated Carbonation Technology to mitigate reactive industrial waste and soil contaminants with carbon dioxide. The company's lightweight aggregate is certified in compliance with UK and EU standards for use in concrete and readymix cement [18]. Lignacite, a sustainable masonry company, manufactures the 'Carbonbuster' masonry block using Carbon8 aggregates [19].

Carbon8 claims to be the first commercial scale carbon negative concrete manufacturer. Whilst the net carbon impact of the manufacturing plant may be negative, this neglects the embodied carbon of the waste materials introduced into the process. Primarily, Carbon8 process should be viewed as a waste mitigation technology and is limited by the availability of suitable industrial waste.

BLUE PLANET

Blue Planet, based in the San Francisco Bay Area, has progressed through two principal technologies during its existence. The initial technology was based on biomimicry, taking as inspiration the biomineralization by aquatic organisms of seawater calcium and dissolved bicarbonate.

Blue Planet's current approach combines saltwater and freshwater sources with flue gas carbon capture [20].

• Seawater is pretreated by nanofiltration to remove magnesium ions and freshwater is derived from municipal wastewater with a calcium ion concentration exceeding 2000 ppm.

• The capture process involves diffusion dialysis using an ion exchange membrane permitting sodium-hydrogen ion exchange. As sodium and hydrogen ions have the same charge but differing osmotic potentials, the salinity gradient drives the formation of an acid solution on one side and an alkaline solution on the other. This is analogous to the electrolytic processes used in Calera technology, but generation of alkalinity is directly coupled to the salinity gradient in this case rather than taking power from the grid.

• The alkaline solution is used for absorbing carbon dioxide from the flue of an existing cement plant or power plant, yielding a bicarbonate solution using the 3M Liqui-Cel hollow fiber vapor-liquid contactor [20].

• This solution is introduced to the calcium ion solution, pre-seeded with raw aggregate, yielding a microstructured rhombohedral calcite.

• Before coating, the resulting aggregate is neutralized using the acid generated in earlier steps and excess CO2 is recycled.

Blue Planet assembles pre-fabricated modules at their site for rapid installation into plants with almost all components being contract manufactured or supplied by existing industrial manufacturers. During operation, Blue Planet estimates a parasitic load of 10% on the plant to power pumps, with the remaining energy derived from the salinity gradient [20].

Arguably, the overall calculation of carbon emissions should include a contribution from the energy involved in generating the salinity gradient if it derives from desalination. Provided that aggregate production does not exceed water treatment volumes at a given location, Blue Planet's approach could be viewed as carbon negative by upgrading municipal and industrial waste streams.

Alternatively, for coastal areas with access to freshwater and saltwater, Blue Planet's technology may be viewed as a special case of osmotic power generation coupled to an industrial process. Osmotic power has been trialed in Norway (Statkraft, 2009), where a pressure-retarded osmosis prototype was deemed to be uncompetitive for scale-up even in the country's supportive tariff and regulatory environment, and in the Netherlands (Blue Energy, 2014), whose geography facilitates integration of reverse electrodialysis into existing flood defences [23,24].

Blue Planet has currently commenced selling to low-volume customers through Sakrete at $60/tonne wholesale and $100/tonne at retail [20]. The price charged for their contribution to ramps and parking structures at the new San Francisco airport terminal is $100/tonne, which reflects shortages of aggregates in California. An unexpected benefit of the fine structure of the material is the 94% reflectance, potentially reducing the heat island effect of the built area.

Blue Planet is currently developing a 2 MWe pilot plant in Tampa, FL, on the site one of the largest desalination plants in the US [20]. They expect to make 21,000 tonnes of aggregate during the first full year of operation. Skanska is considering engaging with Blue Planet in a green highway demonstrator in Florida. Due to the carbon negative nature of the concrete, transportation of aggregate over longer distances and from fewer sites may still be preferable to local quarrying, albeit with significant consequences for road wear. Therefore, surplus from the existing Florida site may in the future be accessible to The Ray.

RECOMMENDATIONS FOR THE RAY

Innovia recommends that the foundation further investigates the possibility of using low carbon and carbon negative concrete and cement on The Ray in two stages. Firstly, The Ray can use available low carbon concrete as a public demonstration for expansion projects at the visitor center. Secondly, when there is an opportunity, The Ray can use carbon negative concrete for any future construction on the road itself or at corporate partner sites.

As an immediate next step, Innovia recommends working with CarbonCure, who has commercially available products approved for structural use manufactured in the Atlanta area and who are keen to engage in a collaborative process of revolutionizing the environmental impact of cement, concrete and aggregates.

Supporting the development of this industry will be challenging as regulatory bodies are conservative and development times are too long for most venture capital investments. The Ray is uniquely placed to facilitate a network between the companies described above, traditional industry organizations and regulatory authorities.

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[8]Water Savings In Concrete Made From Solidia Cement™, April 24, 2014 Authors: Vahit Atakan, Ph.D., Director, Research and Development; Jitendra Jain, Ph.D., Senior Research Scientist; Deepak Ravikumar,Ph.D., Research Scientist; Larry McCandlish, Ph.D., Senior Research Scientist; and Nicholas DeCristofaro, Ph.D., Chief Technology Officer, Solidia Technologies
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[15]Innovia interview with Robert Niven, Founder/CEO, CarbonCure
[16]Innovia interview with Prof Richard Riman, Founder, Solidia Technologies
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PIEZOELECTRIC ENERGY HARVESTING

- If all the roads in the US used piezoelectric technology to harvest energy they still wouldn't produce very much energy
- Piezoelectric technology suppliers have given misleading information on the available energy, sometimes suggesting physically implausible values
- Solar power technology available today can produce more energy for a given length of road than the piezoelectric technology is predicted to achieve even in very optimistic predications
- At this time, Innovia does not recommend pursuing piezoelectric technology as a method of energy generation, and this recommendation is unlikely to change in the future

Piezoelectric materials can harvest energy from the environment by generating an electrical pulse when subject to a deformation (compression or bending). There are a variety of piezoelectric materials available, the most common being PZT (Lead (Pb) Zirconate Titanate) [1]. Other materials include single crystals such as quartz, piezoceramics, thin films and screen-printable thick films based on piezoceramic powders and polymeric materials such as polyvinylidenefluoride (PVDF) [2].

Piezoelectric energy harvesting is most suitable when a very small amount of energy is needed in a place where it is difficult or inconvenient to supply electricity in another form, such as from a battery, a solar panel, or the grid. Current applications include wearable devices such as heart rate monitors and pedometers [3,4], and automotive tire pressure sensors.

Piezoelectric road energy harvesting aims to collect the energy lost in the road in the form of deformations and vibrations, and two types of device have been proposed: compression based systems [5] and vibration based systems [6].

To understand whether piezoelectric road energy harvesting is technically viable, it is critical to estimate the energy that the system might produce. An absolute upper limit on the energy that can be harvested by the piezo system is the energy that a vehicle loses due to rolling resistance – about 1 MJ/km for a heavy truck [7]. For a traffic flow of about 600 heavy trucks per hour, this gives an upper limit of ~150kW/km.

However, most of that energy loss goes into deforming the tires. Using typical compression moduli for asphalt pavements and the average compression caused by a load, the maximum power that can possibly go into pavement deformation is estimated as about 16 kW/km [8,9]. We would then only expect a small fraction of this to be recoverable by a piezoelectric device in the road.

Vendors of piezoelectric energy harvesters have

COMPANY	ESTIMATED POWER PER km (WITH ~600 VEHICLES / HOUR)	COMMENTS
Genziko [10]	13MW / km	Physically impossible – well above the energy lost due to rolling resistance. Estimated cost of $27M/km.
ODOT (Treevolt / Poweramp) [11, 12]	486kW / km	Physically impossible – well above the energy lost due to rolling resistance.
Innowatech [13]	150kW / km	10% of the energy lost to rolling resistance, so just plausible, but it's very unlikely this much energy is going into deforming the pavement. With Innovatech's cost estimate of $650k per km, this just gives a plausible but still high electricity cost of ~$0.20/kWh.
Virginia Tech [14]	0.5kW / km	Probably the most realistic estimate of energy output, and far too low to make an economically viable system.

made estimates of the power output per km. Although they all use roughly the same traffic assumptions of ~600 heavy vehicles per hour, the estimates vary wildly. As none of these technologies have been trialed or even had their claims of energy density per module verified, these claims should be viewed with skepticism.

Only the power estimates at the lower end (Innowatech and Virginia Tech) seem plausible to Innovia as other numbers appear to exceed the limits of available energy. These numbers all rely on at least 600 heavy trucks passing every hour, with the energy available dropping sharply for lighter vehicles or less frequent traffic.

The only energy estimates that have been independently verified are the piezostack components of Innowattech's system. They were tested by Virginia Tech and found to produce power densities of 250W/ft^2 when subjected to a load similar to the mass of a large truck [2]. For a standard highway with a width of 7.4m (two 3.7m lanes), and 8"x 8" units placed nose to tail in pairs along this, this corresponds to 300 kW/km if the devices were all continuously activated. However, when in use the devices are only activated for a short time and only some of them are active at any one time. This is called the capacity factor.

The capacity factor can be thought of as the power pulse width (how long the piezo unit is generating energy) divided by the time between vehicle axle hits. The 600 trucks per hour quoted above and a power pulse width of 0.1s from the Virginia Tech data gives a capacity factor of ~9%, using a vehicle with wheelbase of 11ft and a vehicle speed of 60 mph and vehicle frequency of 600 trucks per hour. The highest estimates for traffic of heavy vehicles with short wheelbases (or many axels) can give capacity factors of up to 30%.

This gives an upper limit of 90 kW/km during actual use for the highest power piezo systems that have been demonstrated. Somewhat higher values may be feasible using vibration based systems with micro-scale piezoelectric materials to extend the duration of the power pulse and hence increase the capacity factor.

Innovia's best estimate of the available power using the vendor's data and assumptions is ~0.5-15 kW/km, from Virginia Tech and Innowattech's estimates, using current piezo modules. This upper limit corresponds to nearly all of the energy Innovia estimates is likely to be transferred from the truck to the pavement, which is likely an unfeasibly high efficiency. In practice, this could easily be 10 times lower, which would reduce the estimate to the range found by Virginia Tech and UC Berkeley (0.05-1 kW/km). This depends on the losses due to the pavement overlaying the piezodevice, and the amount of the rolling resistance that is actually transferred to the road, but this has yet to be properly tested and verified.

An independent report for the California Department of Transport [12] that evaluated the technologies listed in the table found that for all vendors (Innowatech, Genziko and Poweramp) some of their claims about the performance and cost of their technologies were mutually exclusive. This means that under a set of sensible assumptions for piezo module performance and traffic rates, either their energies and lifetimes are far too large, or their estimated LCOE and capital costs are far too small.

The report recommended a more thorough assessment of the technologies, and believed that for the technology to have any chance of competing with other forms of renewable energy such as wind and solar, it would have to:

- demonstrate an increase in power density of at least 20% per module to 400 W/ft2. This corresponds to a "nameplate" power density (i.e. power density if constantly stimulated at 100% efficiency, so does not include capacity factor) of at least 1,800 kW/km

- be used in areas with very high traffic rates composed largely of heavy vehicles
- have technology lifetimes of 10-25 years when installed. Current estimates are for a 2 year life
- have a capital cost of <$5,000 per km and a LCOE of <$0.2 per kwh

None of the current technologies can currently fulfill all of these requirements under a sensible set of assumptions for operating conditions. This scenario also ignores the fact that if the system leads to any increase in the amount of energy lost from cars to the road (to increase the energy available to the piezo system), this is likely to decrease engine efficiency and lead to increases in CO2 emissions from the vehicles.

The claimed costs of these systems also varies widely from $650k to $27 million per km [12]. However, due to the very early stage nature of most of this technology, these estimates and the associated estimates of LCOE are likely to be unreliable. There remain large uncertainties around the actual power outputs of the systems, the system lifetimes and actual system cost.

For comparison, a 1km solar array using commercially available technology the same width as the road (7.4m) would produce 1.1 MW/km peak, at a capital cost of approximately $3.7 million/km. It is likely to take many years of development for a piezo system to reach the targets outlined above, and it is unlikely to ever be possible. Even if these targets are met, piezo's overall energy generation and cost would only be marginally better than today's solar power, and its overall national or global energy generating potential would be vastly less than solar or wind power.

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SOLAR POWER

- Solar energy is by far the world's most abundant renewable energy source, and is one of only a few with the potential to provide a significant proportion of the world's energy needs

- A strip of solar panels all the way along the I-85, about 20 m wide, could power all the vehicles on the road, assuming they were all electric

- We think solar power must be a part of The Ray

- Potential solar projects for The Ray include:
  - A large solar farm at Exit 6
  - Solar noise barrier & solar powered lights on West Point Bridge
  - Solar canopies in nearby parking lots
  - Glare reducing central highway barrier

Solar energy generation technology includes any technology that harvests energy from the sun. The three main types of solar energy generation technology are [1]:

- Solar thermal, where a fluid is heated and used for heating or cooling applications
- Concentrated solar thermal (CSP), where a fluid is heated to high temperature by concentrating solar power through lenses and mirrors and used to produce electricity
- Photovoltaic (PV) technology, which exploits the photovoltaic effect in inorganic or organic materials to produce electrical energy

SOLAR THERMAL

Different solar collectors can be used depending on the climatic conditions and application, which include:

- Production of hot water for domestic use
- Solar heating and cooling for buildings
- Solar heating or refrigeration for industrial processes

The temperature reached by the fluid has a large impact on determining the suitability for a certain application.

Thermal storage is of paramount importance for all these applications and can be aimed at storing energy only during the day or between seasons [1]. Intermittency problems mean that it needs very good thermal storage or additional back-up systems. The maximum availability of energy might not be in phase with the maximum energy demand. To maximize efficiency and to minimize the costs of storage, the application needs to be close in space to the energy harvesting location.

Innovia does not believe this technology is suitable for The Ray.

CONCENTRATED SOLAR THERMAL (CSP)

Different types of concentrated solar thermal technology can be used depending on the conditions and details of the application. The main types of concentrators are parabolic troughs, linear Fresnel reflectors, central receiver/power tower and dish systems. Electric energy can be produced through the Stirling and Brayton cycles.

Both large scale and distributed applications exist, but larger scale plants benefit from economies of scale. Thermal storage systems also have an important role [1]. Suitable mostly in areas with high normal irradiation (i.e. very few clouds), Georgia is not among the most attractive sites for this type of technology.

Land consumption and impacts on flora and wildlife during the build-up are sources of environmental issues, as well as the construction of steel-intensive structures. A lot of water is often required to maintain high efficiencies [2].

Innovia does not believe this technology is suitable for The Ray.

SOLAR PHOTOVOLTAIC (PV) TECHNOLOGY

There are several different types of PV technology with different characteristics. Crystalline silicon is the most common type of PV technology and is well developed. It has peak cell efficiencies of 25% for both mono- and poly-crystalline types [3]. Emerging technologies include CdTe (17% efficiency), amorphous silicon (10% efficiency), and Ga-As concentrator cells (40% efficiency).

For all these technologies, efficiencies of arrays of PV cells are typically 50-80% of the efficiency of an individual cell. These arrays or modules typically have lifetimes of 20-30 years [1].

These technologies also require inverters to convert from DC to AC power for usage or transmission, and storage devices that can store power for use when the PV cell is not active e.g. at night.

Intermittency problems mean that solar technologies need very good thermal storage or additional back-up systems, such as batteries. The maximum availability of energy might not be in phase with the maximum energy demand. To maximize efficiency and to minimize the costs of storage, the application needs to be close to the energy harvesting location.

In Georgia the annual average insolation (day and night) is ~160-180 W/m^2 [4]. This means we can generate about 220 kWh/m2/year, assuming a 16% efficient panel.

This is a fairly encouraging figure. If we'd like to build solar capacity to offset the CO2 emissions of vehicles currently using the road, then assuming that the solar power will replace Georgia's current grid electricity (which emits about 0.52kg CO2/kWh), we would need a strip of solar panels ~40m wide along the whole length of the road. This would cost about $33M/mile. This assumes current traffic levels, and we've based the numbers off the current CO2 emissions of 116,342 tons of CO2 per year emitted on the 16 miles of The Ray.

	Technology	Efficiency (cell)		Pros	Cons
		Lab	Comm.		
Established technology	Monocrystalline silicon 	25%	15-20%	High efficiency means less space and supporting structures are needed. Durable (~25 years) Very well understood technology.	Suffer from shadowing effects Expensive production process, a lot of material is lost, very energy intensive. Bulky, heavy, fragile, not very good looking
	Polycrystalline silicon 	20%	13-16%	Less expensive than monocrystalline. Simpler production process. Durable (~ 25 years)	Less efficient than monocrystalline. Fragile, not very good looking
Emerging technology	CIGS 	23%	~9-12%	Not bulky. Can be made flexible.	In general higher total costs. Difficult to manufacture to scale. In certain cases contains cadmium.
	Cadmium Telluride 	22%	~9-13%	More cost-effective than crystalline silicon in multi-kilowatt systems. Low manufacturing costs. Smallest carbon footprint, water use and energy payback. Good performance at high temperature.	In general higher total costs. Tellurium supply limited. Cadmium is toxic (issue of long-term safety)
	Amorphous Silicon 	12%	6-8%	Low manufacturing costs Can be made flexible. In some cases resistant to shading. Very resistant to heat	In general higher total costs. Less durable than crystalline cells

Solar PV technologies. Sources: [9-15]

In a future scenario, we might look to replace all the vehicles on the road with electric vehicles. Roughly speaking, where an internal combustion engine emits 1kg of CO2, an electric motor in its place would use about 1kWh of electricity. In this case, we would need a strip of solar panels 20m wide along the whole length of the road to power all the electric vehicles on it, at a cost of around $17M/mile.

Solar power can mitigate carbon emissions (there are carbon emissions associated with the full life-cycle of the solar panel estimated between about 0.07 and 0.18 pounds of carbon dioxide equivalent per kilowatt-hour [5]) by producing energy which would otherwise be sourced from the grid, and therefore from carbon emitting sources of energy. The typical payback time in terms of energy used for the manufacturing is 1-3 years, depending on cell type and installation location [1].

Solar power installations require the use of land, and it is better to use waste or brownfield land that cannot be used for agriculture. However even on this land there may be trees, and these can interfere with the installation or cast shadows on the panels. Trees also sequester carbon dioxide from the atmosphere. Is it a good idea to cut them down? The answer depends a lot on the type of tree and how much shadow it casts, and it is advised to consider sites on a case-by-case basis [6].

Besides carbon emissions, the protection of the wildlife in the site and the surroundings must be considered as well. Best practices for the preparation of land should be used to avoid excessive soil compaction and alteration in the drainage of water [7].

There are some environmental concerns about the manufacturing process of panels, which depend on the technology, but these are expected to improve over time.

The cost of PV modules has fallen in the recent years, driving down the costs of LCOE. The economics can be quite varied for small, distributed plants and large farms. Moreover local feed-in tariffs can have a large impact on the economics of grid-connected systems.

LCOE for solar photovoltaic systems (dominated by monocrystalline and polycrystalline silicon technology) is $0.21-0.44/kWh for rooftop systems and $0.10-0.38/kWh for ground-mounted utility-scale plants (OECD countries) [1]. The cost is expected to further decrease in the next few years due to steadily decreasing capital costs of silicon technology (today on average $0.36/Wp) [5,6].

The capital cost of polycrystalline silicon cells is about 17% lower than that of monocrystalline silicon (at 2013) [8].

The impact of the cost of panels with respect to the fully installed system is around 60% [9,10].

SOLAR INSTALLATIONS ALONG HIGHWAYS

Solar power has previously been incorporated into highways in a variety of ways.

SOLAR NOISE BARRIER

Integrating a noise barrier with solar panels can provide additional benefits for the same space: both producing power and reducing noise pollution. There are already several examples of systems in Europe using conventional silicon technology. Here the lifetime cost of the noise barrier is partially paid for with the electricity generated by the solar panels [16-19].

A concept using bifacial solar cells to maximize power generated is being developed in a European Commission funded project, aiming for a pilot installation in 2017 [20].

Solar noise barriers that use luminescent solar concentrators are also under development, but at a very early stage. These can help solve issues of exposure direction, where the road isn't oriented in the optimal direction for a solar noise barrier to work effectively. There is a solar noise barrier of this type being trialed by the Technische Universiteit Eindhoven along the A2 highway to assess the economic and technical feasibility of the technology [21]. It uses translucent, colored panels which are

Top: Solar noise barriers close to Verona in Italy.

Source: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/302049/uk_solar_pv_strategy_part_2.pdf

Bottom: Solar noise barriers

http://www.treehugger.com/solar-technology/solar-power-generating-noise-barriers-go-netherlands.html

Source: Oregon Department of Transport (http://www.solarpowerrocks.com/solar-trends/oregons-solar-powered-highway/)

the luminescent solar concentrators that receive the sun light and guide it into the side of the panels which house traditional silicon solar cells. The technology is also being tested by Dutch building company Heijmans, who are comparing one of these LSC panels with a similar sized set of semi-transparent panels holding classical solar cells. The first results show that 1km of energy generating noise barriers can produce enough electricity to supply 50 houses [21,22].

SOLAR CANOPIES

Canopies equipped with solar panels could be used either along the road or in parking lots. Although these can be constructed with standard silicon wafer PV panels, thin film flexible panels are much better suited to this type of application e.g. [25].

Solar canopies along the road have been proposed as an energy generation method for developing countries with high population density e.g. India [26], but the only implementation we have found is a solar panel array covering a bike path along the motorway connecting Daejong and Selong in Korea [27]. Ideally, this system should not cover the whole road, as this would necessitate lighting it during the day. This implementation is probably only beneficial where there are severe restrictions on land for solar panel farms.

Solar canopies in parking lots are easy to implement and the panel can be mounted on canopies that have the additional benefit of protecting parked cars from direct sunlight. There are many examples of existing installations e.g. [28] and it could be combined with an electric car recharging point [29].

HIGHWAY SOLAR PANEL FARMS

Solar farms built on land adjacent to the highway divide into two types: conventional solar farms built on "waste" land e.g. in the median or junction areas, and those built on the land to the side of the highway.

A highway farm that uses "waste" land on the highway exists in Oregon at a highway junction and is used to feed energy into the grid during the day and to light the junction at night [30].

Solar panels could also be installed on land at the side of the highways. For safety, current guidance is that any installation should be at least ~30 feet from the highway. If trees need to be removed to enable the installation then any assessment of the benefits would need to include this carbon impact. As these installations use conventional solar panel technology, there isn't much benefit as technology demonstration, but it is a low carbon and renewable way of producing energy that can either be sold back to the grid for carbon offsetting or used to power items on the highway such as sensors and lights.

SOLAR POWER ON THE ROAD ITSELF

The road surface is replaced by solar panels that then make use of the surface area of the road to produce electricity. The estimated available area in the US is 100,000km^2 which is comparable to total available rooftop area. There are two approaches currently being explored - Solar Roadways [31] and SolaRoads [32]. Both companies currently have trials underway (at Sandpoint, Idaho, for SolarRoadways and in the Netherlands for SolaRoads).

SolarRoadways uses photovoltaic panels embedded in hardened textured glass. These panels also include heating elements to melt snow and LEDs for signaling as well as all necessary electronics for the system, a water runoff system and could be used as a cable corridor [31]. The power output has not been clearly quoted or independently verified.

SolaRoads uses concrete modules with a translucent top layer of tempered glass, about 1cm thick. Underneath the glass there are crystalline silicon solar cells. This technology is currently being trialed on a bike path [32]. The power output of a SolaRoads system is currently estimated at ~7W/m2 , which is much lower than standard solar panels (70W/m2).

The durability and efficiency of the panels under the harsh conditions of highway use has not yet been quantified, In the SolarRoadways project, the heating elements and lighting could use a large fraction of the produced energy. There are currently design challenges around the resistance of the surface and durability, and the cost-benefit analysis is very uncertain at this stage.

Innovia recommends that the Foundation does not explore putting solar panels on the surface of the road itself. The existing trials have little to say about how the panels could be sufficiently durable, and in the case of SolarRoadways, nothing to say about how much energy could be produced. With toughened glass covering the PV cells, that will inevitably become scratched and dirty, the energy produced will undoubtedly be less than a conventional solar panel. Conventional solar panels are only just approaching grid parity, and the cost of electric from a solar road would undoubtedly be much higher, and hence economically unfeasible in the short and medium term. We propose that this time and money would be much better spent on promoting the uptake of conventional solar PV technology on the land around the highway.

Source: http://www.thepowerreport.com/the-power-report/roads-that-generate-electricity/

Innovia recommends that the Foundation does not explore putting solar panels on the surface of the road itself.

RECOMMENDATIONS FOR THE RAY

LARGE SOLAR FARM AT EXIT 6

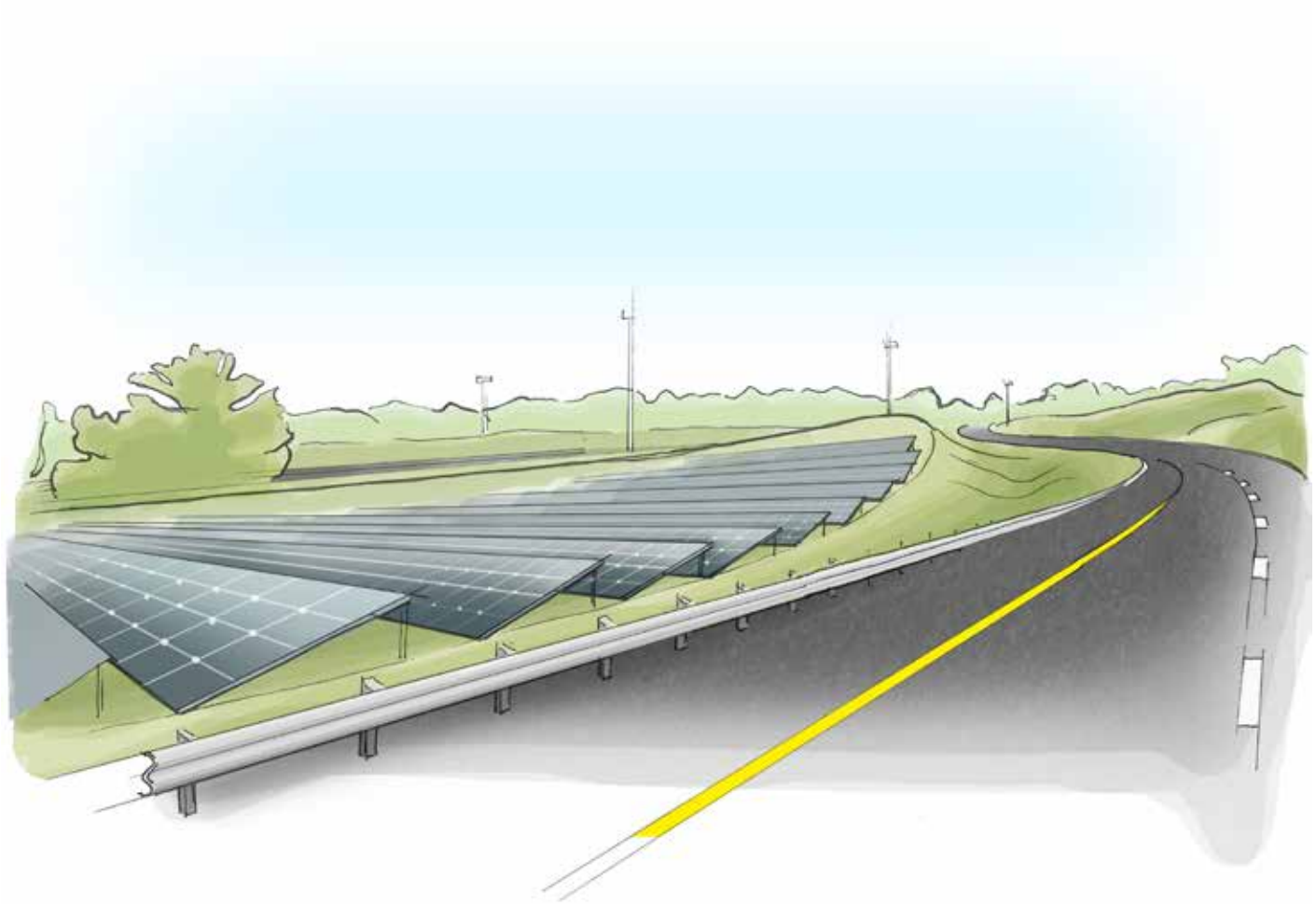
There is a large amount of wasted land within Exit 6. Without the north facing slopes, or the areas with trees, we estimate there's around 70,000m^2 available for a solar farm. This is enough for a solar farm of around 11.2MWp, depending on the final available land area, which would cost around $37M [59].

In terms of size, this is on the top end of corporately funded solar projects. Google has a 1.9 MW PV array [60] covering the rooftop area of its main Mountain View campus and solar parking lot canopies. This used 9,212 solar panels each with an area of 1.2 m^2 [61]. The estimated cost for the installation was $13m in 2007, which includes support from the State of California of around $4.5 million [62].

On a utility scale, the largest US solar farm covers an area of 7km^2 and is set to produce 290MW near Phoenix. This project cost a total of $1.8 billion [63].

The figures in the table to the right assume:

- the average insolation in Georgia is about 160W/m^2
- a solar installation is about 16% efficient
- the Georgia electricity grid produces 0.52 kg of CO2 for every kWh of electricity it generates
- the traffic on The Ray emits 116,342 tons of CO2 per year
- for every kg of CO2 a gasoline car emits, an equivalent electric car will use about 1 kWh



Area	70,000 m^2
Peak power in full sunlight (standard test conditions of 1kW/m^2)	11.2 MWp
Installation cost	~$37 million
Energy generated per year	15.7 GWh
Which is enough to power all the traffic on The Ray, if it were electric, for…	~ 2 miles
Or to offset the CO2 emissions of the current vehicles for…	~ 1 mile

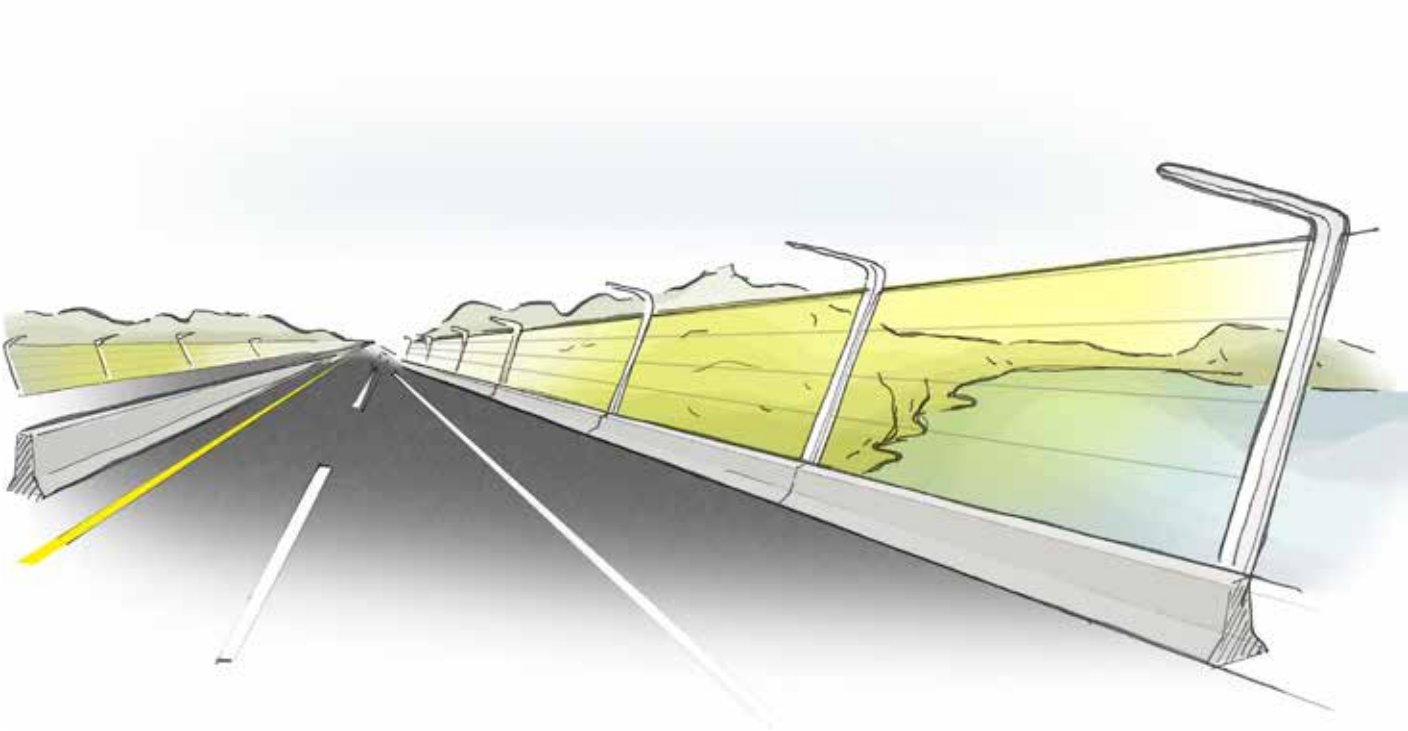
SOLAR NOISE BARRIER AND SOLAR POWERED LIGHTING ON WEST POINT BRIDGE

Translucent solar noise barriers on West Point Bridge could be a striking welcome to Georgia and The Ray, and a captivating demonstration of a novel solar technology. These could use novel (still developmental) luminescent solar concentrator (LSC) technology, or more established thin film technology (e.g. Polysolar). Both of these can deliver an attractive translucent appearance. Although the solar noise barriers would not produce huge amounts of energy, due to their limited area and sub-optimal positioning, they should provide enough energy to power LED streetlights.

As well as providing a striking welcome to The Ray, this could act as a genuine test bed for a high potential next-generation solar technology (LSC).

The barriers would also block traffic noise from the river. This would benefit local wildlife, and may support the use of the Chattahoochee river for leisure and tourism. An article in the August 2015 edition of 'Troup Trends' suggests that the City of West Point are keen to increase use of the river by canoeists, kayakers, paddleboarders and anglers.

As a first step, Innovia recommends contacting Michael Debije at TU Eindhoven [33] and Stijn Verkuilen project leader at Heijmans [34], both of whom are involved in the trial of a combined LSC and noise barrier in the Netherlands.



SOLAR CANOPIES IN PARKING LOTS

Solar canopies in parking lots are a proven technology, with additional benefits of keeping cars in shade on hot days. These could also be combined with an electric car charging point – potentially the one installed at Kia.

DTE energy [36] is working with Ford [37] to install parking lot solar canopies with integrated electric charging. Innovia recommends contacting DTE about the possibility of trialing a similar project on The Ray, either in the visitor center parking lot or in partnership with Kia. Envision Solar also produces solar canopies and integrates them with EV charging [38] and Solairegeneration is one of the leading suppliers of solar parking lot canopies [39].

Source: http://solairegeneration.com

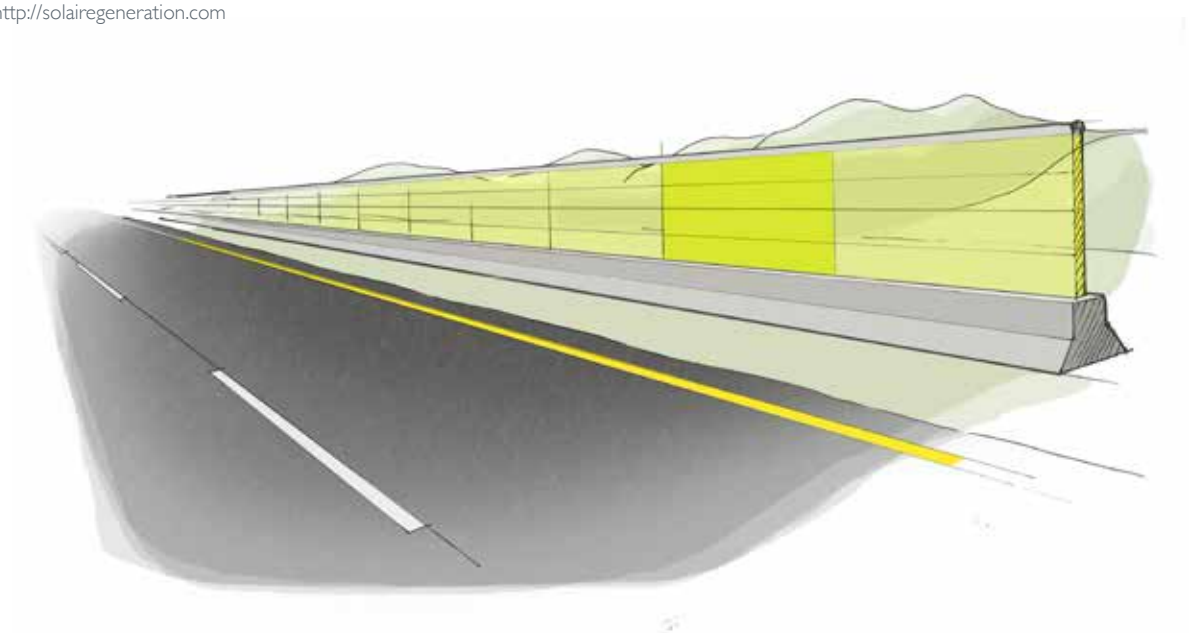
GLARE REDUCING CENTRAL HIGHWAY BARRIERS

Vertical translucent solar panels might be installed in the center of a highway. As well as providing solar power, these would reduce the glare from oncoming vehicles, improving safety [23]. Their translucency allows motorists and especially emergency services personnel to see through to the other carriageway. They might also be effective noise barriers. We have heard that Polysolar is exploring this concept with the UK Department for Energy and Climate Change and Department of Transport.

As the panels are vertical, and not orientated due South, and don't use the highest efficiency technology, the power output will not be optimal. We expect it will be less than a tenth of an optimal photovoltaic array, at about 13 W/m2.

An interesting build on this would be to create an electrically dimmable barrier, that could be dimmed if there was an accident on one carriageway, to reduce the 'rubber-necking' effect.

In itself, this may not be that interesting for The Ray. The large median means that glare from oncoming vehicle is less of a problem. We would prioritize a large conventional solar array over this concept, although as part of the long-term vision a dimmable barrier may be worth exploring.



[1]IPCC, 2011: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1075 pp.
[2]World Energy Perspective: Cost of Energy Technologies, World Energy Council 2013.
[3]Renewables 2015 Global Status Report.
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[10]Opportunities in the Solar Market for Crystalline and Thin Film Solar Cells, Information Network 2015.
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[31]http://www.solarroadways.com/
[32]http://www.solaroad.nl/en/
[33]http://www.oregon.gov/odot/hwy/oipp/docs/solarmanual.pdf

[34]Michael Debije at TU Eindhoven (https://www.tue.nl/en/university/departments/chemical-engineering-and-chemistry/the-department/staff/detail/ep/e/d/ep-uid/20040084/) Tel:+31 40-247 5881 Email: m.g.debije@tue.nl
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[36]http://www.gizmag.com/smart-highway-glowing-lines/34363/
[37]http://www.smarthighway.net/
[38]https://www.swarco.com/norge-en/Products-Services/Smart-roads/Traffic-information/LED-Variable-Message-Signs
[39]http://www.standardsforhighways.co.uk/ha/standards/tech_info/files/MM-ALR_Concept_of_Operations_v2_0.pdf
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[49]http://www.clearviewtraffic.com/astucia/
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[52]http://envisionsolar.com/
[53]http://solairegeneration.com/project/rutgers-university/
[54]http://www.oregon.gov/odot/hwy/oipp/docs/solarmanual.pdf
[55]http://article.sciencepublishinggroup.com/pdf/10.11648.j.ijrse.20140303.12.pdf
[56]http://www.orgalight.com/Orgalight/PageSite/sollar_cells.php
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[58]https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/302049/uk_solar_pv_strategy_part_2.pdf
[59]http://pvwatts.nrel.gov/pvwatts.php
[60]http://blueoakenergy.com/solar-portfolio/google-solar
[61]http://venturebeat.com/2006/10/16/google-builds-largest-solar-installation-in-us-oh-and-bigger-than-microsofts/
[62]http://www.solaripedia.com/13/63/greening_of_google.html
[63]http://www.scientificamerican.com/article/world-s-largest-solar-array-set-to-crank-out-290-megawatts-of-sunshine-power/
[64]http://www.sunearthtools.com/tools/CO2-emissions-calculator.php#txtCO2_3
[65]http://www.aef.org.uk/downloads/Grams_CO2_transportmodesUK.pdf

WIND

- Wind is a well-established renewable energy technology with large scale potential
- However Georgia is not sufficiently windy for wind power to be viable
- Harnessing the energy from the wind created by traffic is not a sensible method of energy generation

Wind power is a well-established form of renewable energy that converts the kinetic energy of moving air into electrical energy. The most efficient and common form is a horizontal access turbine. These are used for all large-scale wind power installations and can generate from 1.5-7.5 MW per 100m high turbine [1]. Vertical axis wind turbines do exist for smaller scale e.g. domestic applications but they are much lower power (55kW) than horizontal axis turbines, albeit more compact (2-6m high) [2]. None of the more novel designs available have been shown to reliably and cost-effectively generate energy [3].

For wind power to be effective, you need at least 5-10m/s average wind speed [1]. Lower wind speeds can lead to energy losses because of how the turbine functions [4]. The Ray is not situated in an area with good wind resource (<4m/s average) so the use of standard wind farms in the vicinity is likely to be of limited use. The state of Georgia is not pursuing any onshore wind energy, preferring offshore wind farms [5]. In Georgia, wind power cannot compete with solar power either on a power per land area or on a power per dollar basis.

Wind power driven by turbulence from passing traffic has been proposed but there is little verifiable technical evidence for these claims. Computer modeling has shown that vehicle turbulence doesn't extend vertically much beyond vehicle height and may not form suitable wakes [6]. Adequate wind speeds are unlikely to be achieved at a safe distance from the side of the road, and is only likely to be at all effective if the wind turbines were within a few cm of a long convoy of large trucks.

Wind energy street lights have also been proposed, but solar powered LED street lights are much more suitable for The Ray due to the large available resource, lower cost and later stage of technical development. The only commercially available wind power street lights also incorporate solar panels [7] and the added benefit of such a small, low power turbine is unclear.

Although wind power in a promising technology in other areas, we do not recommend it on The Ray.

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2.http://cleantechnica.com/2014/04/07/vertical-axis-wind-turbines-great-1890-also-rans-2014/
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4.http://www.goodenergy.co.uk/generate/choosing-your-technology/home-generation/wind-turbines/wind-turbine-faqs
5.http://blog.cleanenergy.org/2014/07/01/11-reasons-wind-energy-will-work-for-georgia/
6.http://energy.mae.cornell.edu/vit.html
7.http://www.eets.co.uk/solarandwindpoweredlightingsystems/default.htm

PAVING TECHNOLOGY

- Existing technology can almost close the materials loop for reclaimed asphalt pavement. Innovia recommends using highly recycled pavement in resurfacing projects on The Ray and challenging any regulations that limit its uptake

- Replacing fossil fuel based products in the asphalt mix with renewably sourced binders reduces the dependency of road building on the fossil fuel industry. These technologies are at an early stage and require support and investment to scale. A demonstration at the visitor center of carbon negative binders from the Bio-Adhesive Alliance would be a productive first step

- Using waste destined for landfills in roads is an interesting long term goal, but the benefits of this will become less clear as more plastic is recycled into higher value applications

- Innovia recommends supporting existing projects in Georgia to recycle old tires into rubber-modified asphalt as a first step

- In the long term, The Ray might participate in landfill mining in LaGrange

The road surface defines the road user's exp erience. The interface between the tire and pavement is crucial to traction, rolling resistance, noise, wear and the smoothness of the ride. A broad range of strategies have been pursued to mitigate the environmental impact of producing asphalt pavement. Sustainable paving materials broadly fall into three categories:

- **Reclaimed asphalt pavement** – minimizing waste by ensuring all asphalt used on the roadway is suitable for recycling and that as much as possible is recycled

- **Renewable binders** – binders sourced from biological wastes are renewable, allowing paving to be further decoupled from fossil fuels

- **Repurposing waste as binders** – the environmental impact of landfill sites may be mitigated by repurposing existing plastic and rubber wastes

In addition, the impact of road surfacing and maintenance will be discussed briefly.

THE COMPOSITION OF A ROAD

The typical structure of a road is represented on the right. The roadbed or subgrade is leveled foundation soil upon which the road is built. Above this are the base (and subbase) layers, which consist primarily of stone and aggregates at various degrees of fineness and compaction. These base layers play the major role in load bearing and load spreading. On an interstate highway, these layers are engineered to handle freight traffic over a 50-year lifetime. On most roads, the surface course or wearing course consists of several layers of asphalt, a mix of aggregates and bituminous binders. On concrete roads, the wearing course consists of prefabricated concrete slabs.

Roadways in the US are a mix of paved asphalt and concrete. Whilst approximately 60% of highways are concrete, 90% of all paved roadways are asphalt [1, 2]. The Ray's road surface including on-ramps and shoulders includes a mixture of both surfaces. Whilst concrete road surfaces are more expensive to build, they have approximately double the lifetime of asphalt pavement before requiring resurfacing. Life cycle analyses suggest that for an interstate highway, the long-term emissions gain from reducing maintenance is offset by the initial emissions cost of construction and materials. [3] Two modes of pavement-vehicle interaction influence fuel consumption. The first is roughness-associated excessive fuel consumption; regularly maintained asphalt is smoother than concrete, which roughens over time, making fuel economy worse. The second is deflection-associated excessive fuel consumption, where uneven roads cause a bumpier ride as a result of wear and road firmness; concrete roads wear less over time resulting in lower deflection effects. Although heavily influenced by other factors, concrete roads appear to have a better overall

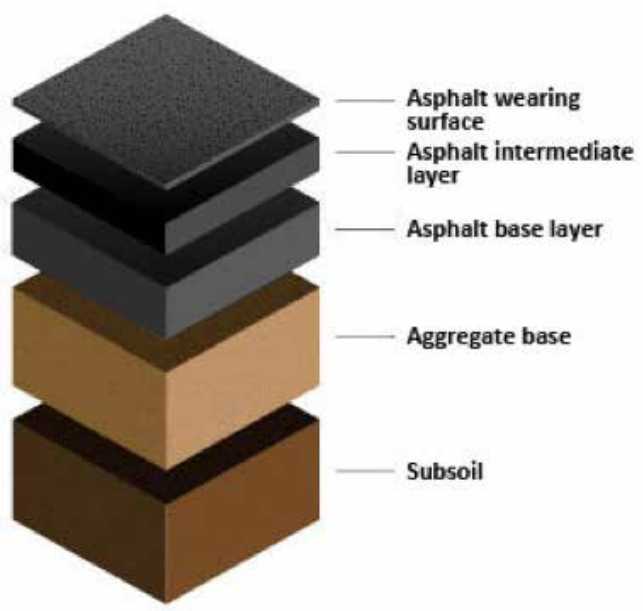

Figure 1: Layers of an asphalt road [1]

impact in a 50 year timeframe considering both approaches, supporting the case for firmer road materials [4].

Low carbon and carbon negative cement, concrete and aggregates are discussed in a separate section of this report and will not be considered further here.

The American Association of State Highway and Transport Officials (AASHTO) is responsible for setting testing and composition standards for materials alongside the American Society for Testing of Materials (ASTM). The Superpave volumetric mix design (AASHTO 323) acts as a gold standard for asphalt specification in the United States.

RECLAIMED ASPHALT PAVEMENT

Reclamation of asphalt is a widely used process in which asphalt from a road surface, which is being repaved or decommissioned, is ground down into binder-coated aggregate. The asphalt may be reused on site or transported elsewhere. In 2010, the US produced 400 million tons of virgin asphalt compared to 73 million tons of milled, reclaimed asphalt [5]. In-place pavement recycling systems now permit integration of reclamation, milling, hot mix and laying into a single process. The Federal Highway Administration estimates that 80-85% of surplus reclaimed asphalt is already being reused elsewhere [6]. This suggests that, in the short term, the paving industry is already maximizing this route for reducing environmental impact and The Ray can simply make use of the existing technology. Asphalt mixes with at least 60% RAP are significantly cheaper than virgin mix, 100% RAP costs 30% less than virgin mix. [7]. In 2014, the City of New York allowed 100% RAP mixes on city streets and all new paving under city jurisdiction must use at least 30% RAP. They are expecting savings of $2.3 million annually. [7]. Hamburg, Germany, switched from 50% recycled asphalt pavement (RAP) to 100% warm rolled RAP asphalt, saving 30% on road resurfacing in the process. They achieved this by a restricted tender relying on the industry's own innovation [8].

The price of bitumen broadly tracks underlying oil prices, hence any long-term reduction in extraction or introduction of carbon tariffs will favor reclamation over virgin materials. Furthermore, if there is an overall shift in the long-term from road building activities to road maintenance, pavement reclamation will become increasingly the dominant activity in the industry. However, this presents a technical challenge to the industry.

Oxidation over time of unsaturated hydrocarbons present in asphalt makes older, reclaimed pavement more brittle and prone to cracking than virgin asphalt. This places an upper limit on the proportion of reclaimed pavement that can be included in the asphalt mix without modification. The Federal Highway Administration observes that many states limit the use of more than 25% reclaimed pavement in hot mix asphalt [9]. In 2009, of 35 state transportation departments allowed to use up to 25% RAP in the intermediate layer, only 10 actually use it. 20 Departments are allowed to use up to 25% in the surface layer, whilst less than 5 do that [7].

Figure 2: Pavement recycling system [4]

Innovia recommends supporting efforts to raise the proportion of reclaimed asphalt pavement that may be used in hot mix asphalt across the nation and to ensure that regulations are based on fair tests of material performance and not fixed compositions.

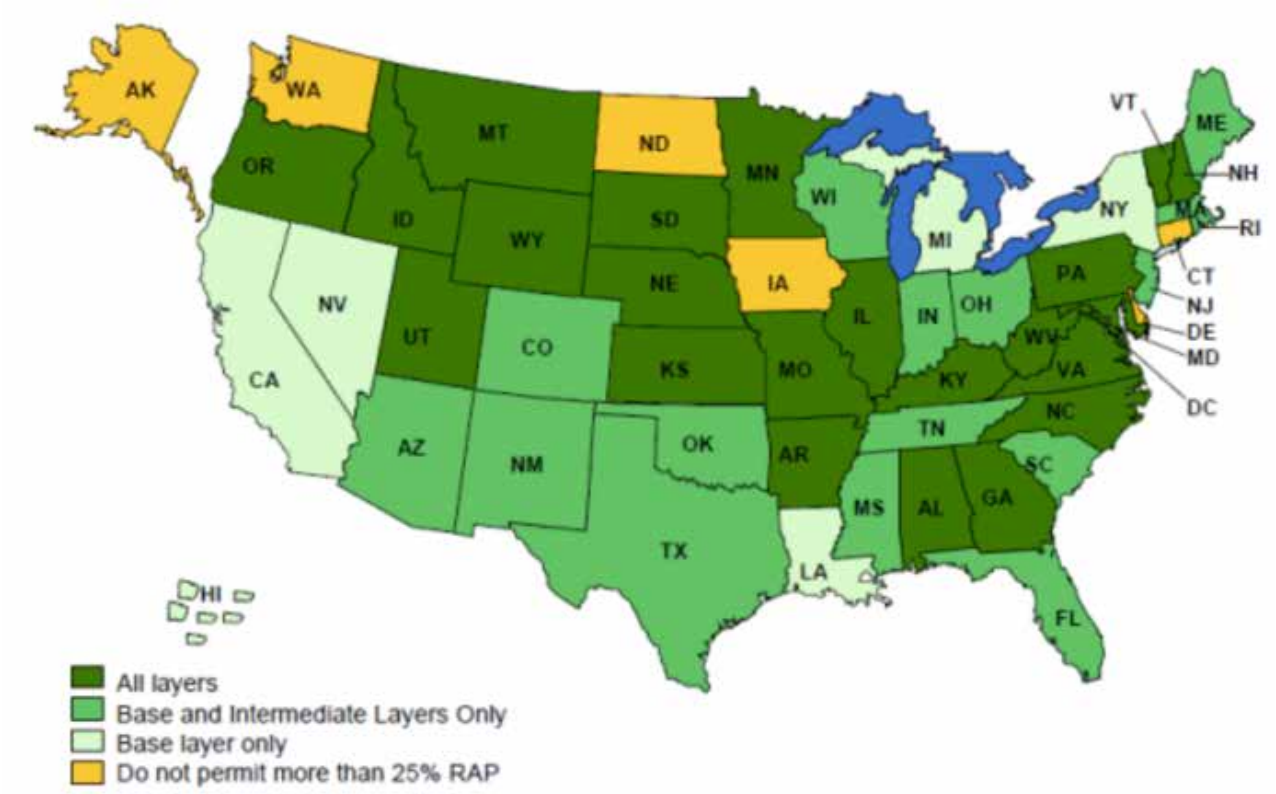

Figure 3: State permission for use of 25% recycled pavement in different road layers in 2009 [9]

RENEWABLE BINDERS

Sourcing of binders for asphalt from fossil fuels is not a long-term sustainable strategy. The potential to use binders from renewable sources is being explored at a very early stage. Crucially, this activity must not displace food crops, but must integrate into the existing agricultural supply chain. Several routes that have been pursued including the use of agricultural byproducts that cannot be reused by farmers and the reuse of food waste where it is not recycled as feed or forms part of a biogas project. Bioasphalt from food wastes include vegetable oil, waxes, algae and lignin [10, 11, 12]. These technologies are in an early stage and limited on-road trials have been carried out. One company using hog manure as a route to bioasphalt stood out as a potential partner for The Ray.

Hog manure is a serious agricultural waste challenge. A hog produces about four times as much waste as a human and most farms are permitted to store concentrated waste in lagoons open to the air. These lagoons pose a contamination risk to watercourses. As antibiotics are a constituent of hog feed, communities living near livestock operations and waste have been found to contract antibiotic resistant MRSA at elevated rates [13]. In addition to local impacts, untreated wastes generate methane, which has 25 times the global warming potential of an equivalent mass of CO2. There are several approaches to tackling this challenge including shipping a larger proportion of hog wastes to feed growers as fertilizer and collecting the methane for biogas.

The Bio-Adhesive Alliance (BAA of Greensboro, NC) use hog waste to manufacture renewable asphalt binders. Hog waste is processed thermochemically, converting lipids to amphiphilic hydrocarbons that serve as surfactants within the asphalt mix. Following fractionation of the desired components, the materials are cross-linked to improve rheology [15]. Nitrogenous compounds, phosphates and potassium are byproducts that can be resold as dry fertilizer. The bioasphalt product has been tested at an accelerated loading facility and conforms to Superpave performance standards.

Two possible product routes include a complete replacement of fossil fuel binder and an enriched reclaimed asphalt pavement mix. The latter product is 10% rejuvenating biobinder by weight and permits a 45% recycled pavement to have the properties of a 15% pavement. BAA estimate that they are sequestering 60% of the methane from hog manure making the final product carbon negative. In addition, the binder permits a lower temperature for mixing (15°C below hot mix asphalt), further reducing carbon emissions. BAA remain at pilot scale, permitting the batch production of binder sufficient to manufacture a truckload of pavement. Innovia recommends supporting BAA in scale up and using their product as a demonstrator at the visitor center.

A key challenge with any waste remediation technique is to ensure that eliminating a limiting waste does not result in a large-scale expansion and further detrimental impacts. Currently, the scale of Georgia farms has been limited by stringent containment regulations for waste lagoons above a 7500 hog threshold and reducing for larger farms was discussed at state level in 2012-13 [16].

REPURPOSING WASTE AS BINDERS

The replacement of binders and aggregates in asphalt is a potential route to minimizing waste destined to enter landfills and in the long-term, as landfill mining becomes economically competitive, could remediate historic wastes. It should be noted that bitumen is a waste product from the petrochemicals industry and the asphalt roadway can be seen as a waste remediation effort in its current

form. In the long term, if renewable energy projects are successful, production of bitumen may decrease as the role of oil refining shifts from fuel to materials at a much smaller scale.

A highly successful example of this is the production of rubber modified asphalt. Liberty Tires, the largest tire recycling company in Georgia and nationally, estimates that if 10% of paving projects utilized rubber modified asphalt, all waste rubber would be repurposed [17]. Whilst production of rubber modified asphalt is more expensive and its environmental impact is higher than reclaimed asphalt, rubber modified asphalt may be of particular benefit in sections of the Ray where reduction in noise is important, such as LaGrange, West Point and sensitive wildlife areas.

There are several routes to incorporating recycled tires into the roadway. Conventional asphalt rubber production involves a wet cement process where up to 20% of the asphalt cement is made up of millimeter sized rubber particles, primarily playing a role as chip seal (fixative) for low volume roads and repairs. An alternative 8-12% mix with submillimeter grade rubber particles has been developed to meet the AASHTO M320 standard for future inclusion in performance grade binders and Superpave mixes [18]. A new process developed as a collaboration between Lehigh Technologies, Liberty Tires and Reeves Construction involves a micronized 8% rubber particle mix which has been authorized for use by Georgia DOT. Innovia recommends supporting this latter strategy in Georgia as it provides a high performance road material whilst remediating a significant waste product generated by transportation.

Other polymer modified asphalts are produced at industrial scale. Polymer additives include styrene-butadiene-styrene (SBS) and DuPont's Elvaloy acrylate copolymer resins. Recently, recycled plastics have been trialled as binding agents in roadways in Vancouver, BC and Madurai, India, with concepts for shown for Rotterdam and other locations [19, 20, 21]. Polyethylene terephthalate (PET), a major packaging plastic used in bottles, and low-density polyethylene (LDPE), from plastic bags, were added to asphalt respectively in these trials. Polymer additives can assist in lowering the stiffness of asphalt and also offer environmental benefits through lowering the temperature. This technology is at an early stage and may supplement increased recycling as a route to mitigate plastic wastes. Due to the performance challenges of these new materials, it may make sense to test them on driveways and paths before using them on the highway. Innovia recommends waiting for further trials of these technologies. In the long-term, landfill mining exercises may start on a larger scale in the United States, offering an opportunity to mitigate historic wastes. Upon completion of the landfill methane program in LaGrange, this may be an opportunity for The Ray in partnership with Interface and Milliken & Company [22].

OTHER INNOVATIONS IN ROAD SURFACES

Innovia notes that a wide range of other innovations are happening in road surfaces and paving. These are described briefly here and Innovia recommends observing their ongoing progress.

- As described above in the description of polymer modified asphalt and bioasphalt, reducing the temperature of hot mix asphalt to create a 'warm mix asphalt'. Technologies for this process are reviewed by the European Asphalt Pavement Association [23]. Cold processing is also possible although this is largely focused on road repair.
- Improving conditions for road workers by reducing the volatile components in asphalt can improve health and safety as well as quality of life. Shell BituFresh is an additive that (above 60 ppm) can radically reduce asphalt odors [24]. Reducing working temperatures also reduce fume exposure.

- Rapid road repair technology has seen considerable progress and include jetpatching vehicles and diamond grinding equipment for concrete pavements [25, 26].
- Early research is being carried out on self-healing pavement including induction heating, microwave heating and encapsulated healing agents [27, 28, 29].
- A range of porous pavements have been demonstrated, such as LaFarge Tarmac's Top Mix Permeable [30]. The benefits of porous roads are rapid drainage and modestly reduced noise. Ultimately, drainage rate of the roadway as a whole for extended rain is determined by the drainage networks into which any porous road feeds. However, the immediate benefit of porous pavement is eliminating water from the surface to reduce risk of aquaplaning and for reduced glare. Porous pavements are currently not suited for highway applications as concerns remain around wear behavior, frost resistance and the higher chance of exposure to materials that may clog the pores during operation and maintenance.

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[3]http://cshub.mit.edu/sites/default/files/documents/Research%20Brief-Apr2014.pdf
[4]http://cshub.mit.edu/sites/default/files/documents/LCA-Brief%204-2012%20CSHub.pdf
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[14]http://www.pavementrecycling.com/products/train.aspx
[15]Innovia interview with Prof. Elham Fini, Civil Infrastructure, North Carolina A&T, and Dr Mahour Parast, President, Bio-Adhesive Alliance Inc.
[16]http://www.ajc.com/news/news/state-regional-govt-politics/debate-on-easing-rules-for-georgia-hog-farms/nbYnG/
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[29]Su Jun-Feng, Schlangen E., (2012), "Synthesis and physicochemical properties of high compact microcapsules containing rejuvenator applied in asphalt", Chemical Engineering Journal 198-199
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ENVIRONMENTAL STRATEGIES FOR THE RAY

KEY PHILOSOPHIES FOR CONCEPT SELECTION

Roads have various negative effects on wildlife, including:

- Habitat loss
- Injury or death
- Lower landscape connectivity
- Pollution
- Introduction of invasive species
- Disturbance

Good solutions for the Ray should

- Ameliorate more than one of the 'negative effects' detailed above
- Aggregate biodiversity
- Rely on local plants
- Prioritize wildlife safety above wildlife visibility
- Require minimal maintenance
- Be an efficient use of money

From these, three key areas have been highlighted:

Firstly, **wildlife road deaths must be reduced** while preserving landscape connectivity.

Secondly, there must be **restoration of habitat** where possible.

And thirdly, the local effects of **pollution must be ameliorated.**

REDUCING WILDLIFE ROAD DEATHS

There were 51,000 auto claims for deer-vehicle collisions in Georgia between 2014 and 2015 – the likelihood of a motorist hitting a deer is approximately 1 in 128. Georgia ranks as 19th on a scale of states where deer-vehicle collisions are most common[1]. In the UK in 2001, the cost to the economy of one human injury from a collision was estimated at £51,000 ($77,000)[2].

However, the cost of animal-vehicle collisions is not just to vehicle occupants. Road traffic collisions can cause severe reductions in animal populations, especially of smaller animals. According to the nonprofit organization Culture Change, "every year our nation's experimenters kill 100 million lab animals, hunters kill 200 million "game" animals, and motorists kill nearly 400 million road animals. Only America's meat-eaters take a larger toll than its motorists [3]"

WARNINGS TO ANIMALS OR MOTORISTS

There are various technologies available, using auditory, visual and olfactory signals, to warn motorists of deer and vice versa. However, both animals and humans habituate to these warnings. Warning motorists, who are driving at 70mph, of deer close to the road may cause more crashes than it prevents.

Deer warning systems are best used on narrower roads with less traffic, and are only suitable for deer – they will not detect smaller animals. They are used

so the road managers can be 'seen to be doing something' but are not particularly effective [4]. They are usually used in conjunction with speed limit reductions.

WILDLIFE CROSSINGS

If wildlife passages are very well known and roads are small, wildlife 'crosswalks' with warnings can be developed [5]. These are only suitable for large mammals. Due to the speed limit and width of road on I-85, this would not be suitable here.

Wildlife overpasses and underpasses have been used in a number of U.S. states[6]. The design of these crossings needs to be tailored to the requirements of the animals that will use them. Underpasses are better for small mammals, reptiles and amphibians; bridges are better for large ungulate species. However, underpasses can be modified to be wide to encourage deer movement, while still having shelves and ledges to encourage small animal traffic. This solution allows the passage of the largest number of animals for the lowest cost: overpasses are significantly more costly.

There are many stream crossings beneath I-85. Retrofitting existing culverts has received a lot of interest – larger culverts can also be made more suitable for aquatic organisms by mimicking the natural stream width and natural streambed[7]. This supports aquatic populations and slows water run-off during floods. Retrofitting existing culverts is also usually less expensive than starting afresh.

There must be substantial incentive for animals to use crossings rather than take the direct route across the road. Good fencing is crucial to ensure that the crossings are used and the motorists are safe [8].

COST ESTIMATE

The cost of a wildlife overpass was estimated at $1,900,000 in 2011[9].

Cost estimates for retrofitted culverts vary dramatically – a lot of this depends on the specific location and the design of the existing culverts. Wider culverts are less likely to get blocked and are more likely to permit deer movement. The cost for a retrofitted culvert has been estimated at about $30,000 [10] on a smaller road, and from new, on an interstate, between $250,000-$750,000 in today's money[11]. However, the Foundation would need to consult the DeerLab (see below) for optimum positioning of the crossings and then speak to a contractor to receive a bespoke quote.

FENCING

Fences are the most effective way of preventing animal-vehicle collisions[4]. They are most effective when used in conjunction with designated animal crossings to reduce the pressure of animals on the fence[12]. Some fences additionally minimize the effect of disturbance, including noise and light pollution on the surrounding wildlife. Public perception of such fences may not be positive – it would need to be in conjunction with good education and perhaps number of deer lives saved.

Wildlife fencing has been successfully employed in various locations around the U.S.[13].

Consideration should be given to methods of removing animals that have managed to get into the carriageways. It is possible to use 'deer leaps' – ramps up the fence on the inside to enable any deer that are trapped to jump out. Other alternatives are one-way deer gates or rangers to dart or shoot deer that are trapped.

The support structure is usually preservative-treated wooden posts and steel wires. The cladding for deer roadside fences is usually rectangular woven locked joint high tensile galvanized steel mesh. Green-colored galvanized mesh is available. The top and bottom selvages should be knuckled. The usual U.S. deer fence height is 2.4m (8'). I-85 along The Ray is a forested area. To prevent as many deer collisions as possible, fencing should be erected along the whole road. However, surveys of deer movement and/or fatalities could be conducted to identify high-risk areas and fence preferentially there.

If a new lane is built, consideration of curb design can help to prevent small animals (mammals, reptiles and amphibians) from getting onto the roads[14]. In addition, fencing should consider both small and large animals. Road fatalities of small animals can have a significant impact on the population[15].

COST ESTIMATE

The cost of deer-proof fencing varies significantly in price. In the U.S., wildlife fencing along highway 93 costs between $26-$41 per meter (giving a total along the whole Ray of $1.3-$2.1m). In the UK, deer proof roadside fencing is estimated at £7.80/m ($12/m, giving a cost of $400,000 total).

The likely amount of maintenance depends on how well the fence is initially planned and the pressure on the fence (e.g. whether wildlife routes are available). Major repairs should not be required if the specification, route and length were well defined initially and the correct materials chosen. However, regular inspections and repair of holes should be made, this is estimated at $500/km per year.

RECOMMENDATIONS FOR THE RAY

Innovia's recommendations are:

For **ensuring landscape connectivity**, modify existing freshwater culverts to provide wildlife underpasses. These should be designed to allow many sizes of species to use them, and should also improve the streambed quality for habitat restoration of aquatic organisms. This stage should occur before the fencing to provide alternative routes for animals and to avoid excessive pressure on the fences. Advice should be sought on the appropriate places for deer transit.

Installing ledges along the inside of existing small culverts will facilitate small animals using them as crossings. The risk of deer collisions is likely to be higher at certain points, but small mammals are more likely to be present along the whole route, so small alterations to all existing culverts will substantially improve the chance of survival.

For **preventing wildlife casualties** on the road – install fencing along the Ray. This could be constructed at areas of high deer traffic; however, the entire route is forested and likely to contain deer. Leaving gaps in the fences allows the possibility of animals getting on to the carriageway and ending up trapped between the fences. Advice on the design of the fences should be sought to ensure they are suitable for all the species that are at risk along the corridor.

KEY PARTNERS

DeerLab at University of Georgia [16]

This laboratory conducts research relevant to white-tailed deer management. They may be able to advise on major deer routes and specific management strategies for the area. They might also be interested in conducting research on any interventions employed on the Ray.

Beem Fence Company[17]

This company builds high deer fences. They don't give cost estimates on their website. It would be worth talking to other interstate managers who have contracted out wildlife fencing to find the companies that they have used.

American Rivers[18]

This organization protects wild rivers, restores damaged rivers and conserves clean water for people and nature. It has funded many projects on restoring riparian environments. They might be a useful contact for advice and funding for improving culverts for fish passage under I-85, which would contribute to the costs of the wildlife underpasses. In addition, their goal of conserving clean water might ally with the bioswale development along I-85.

SPECIFIC NEXT STEPS

1) Speak to DeerLab to find out what information can be provided.

2) Speak to other interstate managers for information on wildlife fencing contractors and culvert retrofitting contractors.

FUTURE DEVELOPMENT

It may be possible to get funding from research groups interested in white-tailed deer management or even from the sale of hunting and trapping licenses.

Underpass webcams could be an important educational tool for the education center, and make this 'invisible solution' more visible to the public.

IMPROVING ROADSIDE HABITATS

There is a public perception in the U.S. that well-tended roads have large expanses of mown green turf. These provide very limited habitats for wildlife, require herbicide use and need frequent mowing, which causes pollution and uses energy.

Mowing requires significant energy input, encourages more plant growth and removes invertebrate habitats. Leaving the cuttings on the soil can lead to fertilization that increases the growth of invasive species or unwanted weeds[19]. Currently, in Georgia, roadside vegetation is managed through a combination of herbicides and mowing.

A barrier to reducing the frequency of mowing is public perception – there is a view that short green grass is optimal. Other reasons given for repeated mowing are to increase visibility of traffic, allow cars to safely leave the road without hitting trees, increase visibility of wildlife by roadside, control state and county designated noxious weed species wherever they occur and preserve the pavement edge (stop plants growing up through it).

Methods of addressing these concerns are as follows:

• Public perception: have a substantial educational campaign

• Increase visibility of traffic: I-85 has very few, very shallow bends

• Allow cars to safely leave the road without hitting trees: using grasses instead of trees will not cause a sudden impact but may have a beneficial buffering effect

• Increase visibility of wildlife by roadside: good wildlife fences should reduce the risk of the wildlife being there in the first place

• Control noxious weed species: fast-growing native species should outcompete these, and slow the growth of woodier plants

• Preserve the pavement edge: the greatest stress to pavement is from tree roots. Grass roots are less damaging.

INTERSTATE PLANTING OR LANDSCAPING

Various states plant floral beds or other visually appealing landscapes. These require substantial maintenance, as the ecosystems are not stable without intensive management. This maintenance may include fertilizer use, replanting, pruning and others. In addition, they often use non-native species which may not cope with climatic conditions or which may become invasive. They also may not provide optimum habitats for native animal species, and are usually more expensive to maintain.

MOW LESS

Currently, grasses like bermudagrass are popular for highway borders. These require frequent mowing and herbicide use. If left to grow unchecked, they would develop seed heads and likely become yellow during the summer before dying back. Education of drivers on the savings made by mowing less would be a good start. As the grass is fairly low, fast-growing tall plants will grow quickly. At the very least, annual mowing will be required to prevent growth of trees and limit spread of tall invasive species, but avoidance of mowing during the summer months allows greater biodiversity[20]. Ecological restoration of roadsides has also been studied in the U.S. [21].

USE A DIFFERENT PLANT SPECIES

Planting a different plant species will look visibly different and should not automatically cue drivers to think about untended highways. Such a plant species needs to be native, drought tolerant and not invasive[22]. The ecosystem should not require much

maintenance, so plants requiring substantial pruning, replanting, fertilization or watering should be avoided.

One possible candidate would be switchgrass. This family of grasses naturally extends across North America, and was a key species in the prairies. It is a tall and fast-growing grass, which dies back over the winter but is perennial. It has a strong educational message: destruction of the prairie lands released a huge quantity of carbon dioxide into the atmosphere.[23] The prairie grasses are important carbon sinks.

Switchgrass has numerous benefits. It has a very extensive root system, which stabilizes the soil and prevents erosion, slows water drainage through the soil. In addition, the sloughing of root cells into the soil is an effective method of carbon-capture – carbon dioxide is used to build the root cells, which are then lost into the soil.

Above the ground, the bulky base of the plants slows surface run-off and surface erosion, reducing sediment in rivers and reducing the risk of flooding. It grows tall, outcompeting fast-growing undesirable weeds, reducing local noise pollution and catching wind blown trash before it enters the watercourses. It has been used by Massachusetts' DOT to manage Japanese knotweed.[24] In addition, as a grass by the side of a road, it will not cause abrupt impacts if cars come off the road. It also reduces local air turbulence (a problem for small invertebrates) and provides substantial new habitats.

Switchgrass has been touted as a biomass crop. However, the area to be cultivated would not payback a biomass burner, and the transport of the crop would be expensive. Furthermore, the discontinuous production of cuttings does not fit well into a business plan. However, if a local biomass plant was available, then the cuttings could be used to generate energy. Mowing of the crop is best done after the first frost to ensure that the rhizomes contain sufficient energy to grow the following year, and that the aboveground cuttings are mostly dead lignin.

Periodic mowing and discing is preferable to open up the lower layer to encourage wildlife. It's recommended to do one third of the area every year (so the whole area is mown over a three-year cycle). Mowing and removal of the cuttings will also remove wind blown trash.

Switchgrass has substantial benefits for carbon capture and habitat formation. However, growth of a monoculture will always limit biodiversity, and so the potential risks and benefits should be carefully weighed up.

COST ESTIMATE

The estimates obtained for switchgrass planting and maintenance are from those wishing to farm switchgrass for biomass production. In 2006, the estimate of production costs was $335.40 per acre[25] (total estimated area of land around the Ray interstate that could be used is around 200 acres, this would give a total cost of $65,000. However, this will be an overestimate, as not all of the land will be seeded, but this estimate does not include contractor costs). This average includes establishment, production and reseeding costs. Harvesting costs will be reduced for the model that could be employed by The Ray.

RECOMMENDATIONS FOR THE RAY

Innovia's recommendations are:

• For **increasing biodiversity** and **reducing energy use**, reduce mowing to biannually (before and after the summer season). Removal of clippings will decrease soil fertility and favor climate-tolerant native plants. This needs to be in conjunction with a strong educational campaign to increase awareness of the reduction in biodiversity and increases in energy and herbicide use with intensive mowing strategies. Testing of a trial stretch with reduced mowing to see the effects on collision frequency could provide ammunition for lobbying for relaxation of the laws around visibility on interstate roads.

• For **carbon capture** and **habitat restoration**, planting test plots of switchgrass would allow testing of habitat and growth potential. These could provide a strong educational message. Pragmatically, planting along the edges rather than median might be less controversial with regards to visibility as switchgrass is a tall, fast-growing plant.

KEY PARTNERS

National Wildlife Federation

This is a national organization committed to conservation[26]. They may be interested in funding projects to protect local endangered species – the Georgia Tech Executive Summary references six endangered species along the 16-mile corridor.

Two Rivers RC&D

This is the local Resource Conservation and Development Council, a nonprofit organization[27]. They have limited funds for grants but might be good partners for the conservation side of the I-85 development.

Georgia Native Plant Society

This nonprofit organization promotes the stewardship and conservation of Georgia's native plants and their habitats[28]. They give grants for research and they form partnerships with communities and public places to establish or restore native plant preserves. They might be useful partners for education about the benefits of less frequent mowing and would be a useful source of information on selection of appropriate plants.

A reference for a list of conservation contractor services for native grasses and forestry is listed in the appendix[29].

NEXT STEPS

The next step would be to calculate the savings if mowing and herbicide use was stopped along The Ray. This needs to include any increase in costs from the cutting of longer grass annually.

FUTURE DEVELOPMENT

Research could be conducted on test plots of switchgrass to assess if there was any effect on collisions, effect on pavement degradation or any other of the concerns that have been raised as reasons to mow interstate edges. This would provide an evidence base for legislation. If there were no adverse effects, The Ray could lobby for such a strategy to be used elsewhere, potentially rejuvenating huge swathes of land into viable ecosystems and capturing large amounts of carbon dioxide.

REDUCING PARTICULATE POLLUTION

Particulate pollution includes soot, fragments of rubber, road dust, oil and heavy metals. The pollutant effect is most severe close to the road[30]. It is known to affect human health and decrease visibility. The Ray is not close to large numbers of houses, so considerations for human health are less important here. However, local particulate pollution can be deposited in watercourses from road run-off: I-85 is in the watershed of the Chattahoochee River. Filtration of the road run-off will have substantial benefits to the local waterways.

DUST SUPPRESSANTS

There have been trials of different compounds applied to the road surface, including calcium magnesium acetate[31] and calcium chloride[32]. The former binds to pollutants; the latter is hygroscopic and creates a surface layer of water to bind the dust. Both are relatively environmentally benign, but the effects are limited and the spray needs to be performed several times a week. The inconvenience of this and the lack of substantial effect mean that we do not recommend this technology.

BIOSWALES

Swales are shallow drainage ditches that are created to carry water during rainstorms. Bioswales are filled with vegetation or compost. The flow path is designed to slow the water to allow deposition of silt and trapping of particulate pollutants including heavy metals, rubber and oil. Bioswales are the most effective way of trapping the largest variety of pollutants. They are also very effective at slowing water run-off during heavy rain, and will be designed to cope with a ten-year flood event.

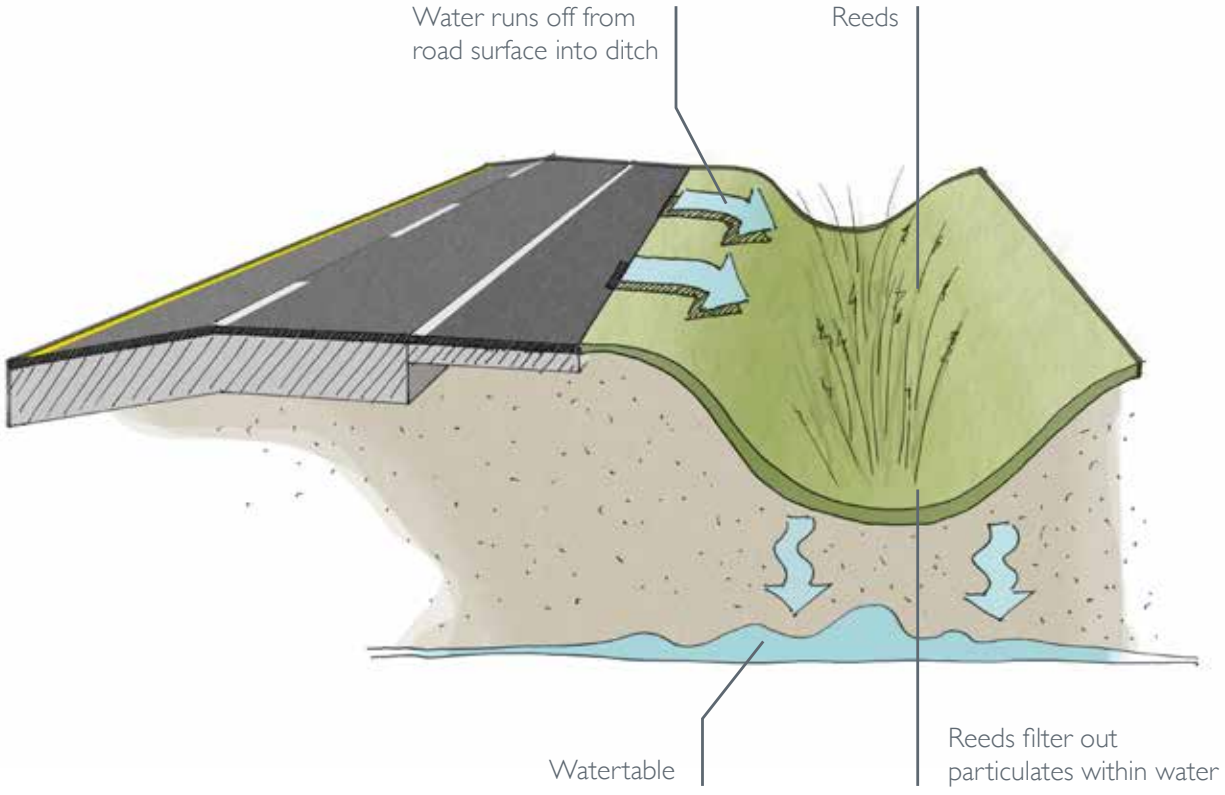
Unlike the culverts, the bioswales are visible to passing motorists and can have a strong educational message behind them. In addition, they can complement the change in mowing policy – occasional cutting of the vegetation is necessary to optimize drainage, but when the plants are cut, their ability to remove pollutants is reduced. Switchgrass is often one of the plants used in bioswales.

Planning of the position of the bioswales will require discussion with local ecologists. They should be positioned where the runoff is greatest. Other considerations include the slope, the area of runoff and the vegetation to use[33]. This information is specific to the region and a tailored design is necessary. In addition, the costs may include several years of management until the ecosystem is relatively stable, and then will have some ongoing costs to ensure continued function. Bioswales can be beautified, as in the Lyons Avenue/Interstate 5 interchange in California[34]. Bioswales are becoming more widely used with many other examples in California[35] and increasing interest in their use in Georgia[36].

COST ASSESSMENT

A case report of construction of two 100' by 6.5' bioswales found costs of $119,000 for installation and a year of monitoring. However, this monitoring was to assess their effectiveness and will have added to the cost.

Costs quoted for bioswales is very variable, from $2.75 per square foot to $89.52[37] in one presentation and around $0.50 per square foot for a simple grass swale[38]. Another comparison of cost estimates gives references for different examples[39].



RECOMMENDATIONS FOR THE RAY

Innovia's recommendations are:

• For **amelioration of local pollution** and **slowing of water run-off**, construct bioswales in key areas along The Ray. Expert advice needs to be sought on the siting of these, the size and the vegetation planted.

KEY PARTNERS

Natural Resources Conservation Service Georgia

This service provides technical assistance on natural resources issues and assist groups implementing soil and water conservation practices to protect the 34 million acres of privately owned land in Georgia[40].

Klopfer Design Group

This group has won numerous awards for their work and has worked both in the U.S. and abroad[41]. They are recommended by the Challenge for Sustainability project[42], which also gives detailed information on the regulatory requirements, financing options and incentives and a list of examples.

Landscape Associates

This company is based in Georgia. They construct commercial bioswales[43].

Chattahoochee Riverkeeper

This nonprofit organization is dedicated to protecting and preserving the Chattahoochee River, its lakes and tributaries[44]. I-85 is within the watershed of the Chattahoochee River, and steps taken to reduce water-borne pollution will aid river health.

SPECIFIC NEXT STEPS

Seek advice on the siting of bioswales, the size of them and the number needed to clean the run-off from The Ray. Once this information is assimilated, a quote can be obtained for the cost of their construction.

FUTURE DEVELOPMENT

Data could be collected on the effect of the interventions on water quality. Research might be funded through angling associations or river conservation associations.

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[2]Department for Transport statistics, UK, 2012 https://www.gov.uk/government/publications/reported-road-casualties-great-britain-annual-report-2012
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[4]Deer and Road Traffic Accidents: A review of mitigation measures: costs and cost-effectiveness http://www.deercollisions.co.uk/web-content/ftp/NFjuly2004rta_rjp.pdf
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[7]Design of Bridges and culverts for wildlife passage at freshwater streams https://www.massdot.state.ma.us/Portals/8/docs/environmental/wetlands/WildlifePassagesBridgeDesign122710.pdf
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[11]Best Practices Manual: Wildlife Vehicle Collision Reduction Study; Chapter 4: Design and guidance of WVC mitigations for large mammals https://www.environment.fhwa.dot.gov/ecosystems/wvc/ch4.asp
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[13]Wildlife-friendly design of the I-70 https://www.codot.gov/news/2013-news-releases/02-2013/new-phase-of-i-70-west-wildlife-fence-installation-underway
[14]Common toads and roads: Guidance for planners and highways engineers (England) http://www.savethefrogs.com/threats/roads/images/toad-road-planning-guide-ARG-UK.pdf
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[18]American Rivers http://www.americanrivers.org
[19]Conservation Verge Trials, Dorset https://www.dorsetforyou.com/conservation-verge-trials
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[21]Ecological Restoration on Roadsides: Examining Ecological and Organizational Feasibility, NL Haan, http://deepblue.lib.umich.edu/bitstream/handle/2027.42/77596/Nathan%20Haan%20SNRE%20Thesis%202010.pdf?sequence=1
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[24]Managing Japanese Knotweed: Two Small-Scale Strategies http://www.ecolandscaping.org/09/invasive-plants/managing-japanese-knotweed-two-small-scale-strategies/
[25]Switchgrass profile http://www.agmrc.org/commodities__products/biomass/switchgrass-profile/
[26]National Wildlife Federation http://www.nwf.org/What-We-Do.aspx
[27]Two Rivers RC&D http://www.tworiversrcd.org
[28]Georgia Native Plant Society http://gnps.org
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[32]Lay the dust with calcium chloride http://www.tatachemicals.com/europe/products/pdf/Calcium_Chloride/information_dust.pdf
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[37]Cost Analysis of Low Impact Development Best Management Practices http://epa.ohio.gov/Portals/41/storm_workshop/lid/CRWP_LID_Cost%20Study.pdf
[38]Grassed Swales http://water.epa.gov/polwaste/npdes/swbmp/Grassed-Swales.cfm
[39]Green Values National Stormwater Management calculator http://greenvalues.cnt.org/national/cost_detail.php
[40]Natural Resources Conservation Service Georgia http://www.nrcs.usda.gov/wps/portal/nrcs/site/ga/home/
[41]Klopfer Martin Design Group http://www.klopfermartin.com
[42]Challenge for Sustainability, Bioswales http://challengeforsustainability.org/resiliency-toolkit/bioswale/
[43]Commercial Landscape Installation Services http://www.laipros.com/services/commercial/commercial-installation/
[44]Chattahoochee Riverkeeper http://chattahoochee.org

DRIVE THROUGH TIRE PRESSURE MONITORING AND INFLATION

- Improperly inflated tires reduce fuel efficiency, increase carbon emissions, and can be dangerous
- Wheelright (www.wheelright.co.uk) has developed a drive over sensor that can measure tire pressures up to a speed of about 10mph
- They are also developing a system to measure tread depth all around and across the tire
- On-vehicle tire pressure monitoring is now mandated for passenger vehicles in both the U.S. and the EU. This may soon obsolete drive over tire pressure sensors
- We recommend a tire monitoring station on The Ray that measures both tire pressure and tread depth. This will gather data on tire inflation habits to inform public policy and drive public awareness
- This data may justify investing in the development of a drive through robotic tire inflation station to further drive compliance with tire pressures

"Every year, the UK sees approximately 25 deaths and nearly 1,500 serious accidents attributed to poorly inflated or defective tyres"[1]

"In the U.S. alone, the Federal Department of Transportation estimates that under inflated tires waste 2 billion U.S. gallons of fuel each year."

Improperly inflated tires reduce fuel efficiency, increase carbon emissions, and can be dangerous. In the U.S. alone, the Federal Department of Transportation estimates that under inflated tires waste 2 billion U.S. gallons of fuel each year. Every year, the UK sees approximately 25 deaths and nearly 1,500 serious accidents attributed to poorly inflated or defective tires.

However it is often difficult or inconvenient for motorists to check and inflate tires, and many motorists do not keep their tires properly inflated [5]. Wheelright [1] claims to have invented a solution to this problem. Drivers simply drive over a pressure mat and within seconds are presented with a readout of their tire pressures on a touch screen interface.

We spoke with Wheelright about their technology. Their first market has been commercial truck depots, to help haulage companies monitor the tire pressures of their fleet. They have one system installed in the U.S. They are speaking with all the major fuel companies, and would like the system to be installed on every fuel forecourt. Wheelright's business model is based on a subscription, and they charge a monthly fee to keep the system maintained. In March 2015 Wheelright installed their first system that is open to the public, at Keele services on

Figure 1: Wheelright tire pressure monitoring system (www.wheelright.co.uk)

the M6 in England [2,3]. The system was free for the public to use and was sponsored by Highways England. This trial will gather data about tire inflation habits that will be used to inform the investment decision on rolling out the technology across the UK.

We also discussed measuring tread depth with Wheelright. They are developing a system that will be the first of its kind, and will measure the tread depth all the way across and 360° around the tire.

It could be interesting to put the technology in the highway itself, to alert passing motorists to low tire pressure. However this would be extremely technically challenging and the Wheelright system is only functional up to about 15mph.

Another interesting development would be a robotic tire inflation station. Motorists could then both check and inflate their tires without getting out of the vehicle, which may further improve tire inflation compliance. We have not seen such a system in development, although the idea is described in U.S. patent application US20110172821 'Automated tire inflation system'. [4]

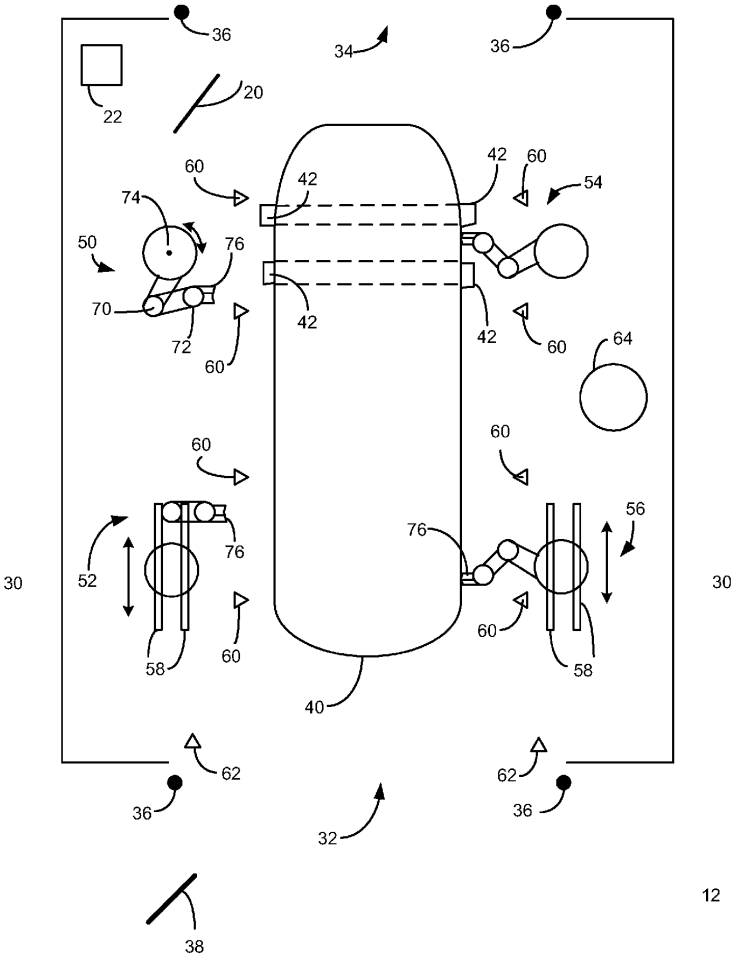

Figure 2 Robotic tire inflation station described in US20110172821

A major threat to the Wheelright tire pressure monitoring system is in-car tire pressure monitoring systems (TPMS). In the U.S. as of 2008, and in the EU as of 2012, all new passenger cars must be equipped with a TPMS. In a few years, this could render a drive-through tire pressure monitoring system obsolete. However we have not seen any suggestion that tread depth monitoring, or auto-inflation of tires, are likely to become widespread in-vehicle technologies. Unless there is a major disruptive innovation in tire technology, a drive through system with these functions is likely to make a valuable contribution to fuel efficiency and safety for years to come.

RECOMMENDATIONS FOR THE RAY

We recommend trialing the Wheelright technology on The Ray, either at the visitor center or the Shell gas stations at exits 13 and 14. Preferably this should include Wheelright's developmental technology to measure tread depth. This trial will gather valuable data on tire inflation habits, which could be used to inform further investment decisions.

This data might then be used to support the investment case for developing a robotic tire inflation station. With recent advances in robotics and machine vision, this seems eminently feasible. The Foundation might help make this happen be bringing together the right experts from Silicon Valley and academia.

[1]www.wheelright.co.uk
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[3]http://www.transportengineer.org.uk/transport-engineer-news/half-of-cv-show-visitors-arrived-in-vehicles-with-under-inflated-tyres/83709/
[4]http://www.google.com/patents/US20110172821
[5]http://www-nrd.nhtsa.dot.gov/Pubs/809-316.pdf

LIGHTING THE RAY

- Lighting on highways has typically used inefficient mercury or low pressure sodium lighting
- Switching to the latest lighting technologies (LED or LEP) can save energy, reduce costs and minimise light pollution
- These technologies have advanced significantly in the last few years. The investment case for them is now very strong and they are being adopted in cities and on highways around the world
- Innovia believes that to be credible a sustainable highway must use efficient lighting technology
- Beyond efficiency, there is huge potential for innovation in lighting, to create a more interactive and responsive highway, and to improve safety
- We recommend three specific projects:
    - Replace all mercury or sodium lighting on The Ray with the latest LED and LEP technology
    - Pilot solar powered LED lights on the bridge at exit 6
    - Trial a smart system of intelligent road studs on a short stretch of highway

Light	Lifetime (hours of operation)	Efficiency (lumens/ watt)	CRI (color rendering index)	Ignition time	Notes
Incandescent light	1,000-5,000	11-15	40	instant	very inefficient, short life time
Mercury vapor light	12,000-24,000	13-48	15-55	up to 15 mins	very inefficient, UV radiation, contains mercury
Metal halide light	10,000-15,000	60-100	80	up to 15 mins	high maintenance, UV radiation, contains mercury and lead.
High pressure sodium light	12,000-24,000	45-130	25	Up to 15 mins	Low CRI with yellow light, contains mercury and lead
Low pressure sodium light	10.000-18,000	80-180	0	up to 15 mins	low CRI with yellow light, contains mercury and lead
Fluorescent light	10,000-20,000	60-100	70-90	up to 15 mins	UV radiation, contains mercury, prone to glass breaking, diffused non-directional light
Compact Fluorescent light	12,000-20,000	50-72	85	up to 15 mins	low life/burnout, dimmer in cold weather, contains mercury
Induction light	60,000-100,000	70-90	80	instant	higher initial cost, limited directionality, contains lead, negatively affected by hear
LED light	50,000-100,000	70-150	85-90	instant	higher initial cost
LEP light	50,000-100,000	70-140	94	instant	Higher lumens per unit than LED, better scaling to high brightness

Sources:
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http://www.reduser.net/forum/showthread.php?59154-Cutting-through-the-hype-surrounding-Light-Emitting-Plasma-%28LEP%29-lamps
http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=3044&context=jtrp

The two most suitable lighting technologies for The Ray are light emitting diodes (LEDs) and light emitting plasmas (LEPs).

LED LIGHTING

LED lighting has an optical efficiency of >100 lumens/watt, which implies energy savings of 60-75% compared to the mercury or sodium lamps widely used in roadway lighting [1]. LED lights also focus light on the highway better, minimizing light pollution.

LED lighting is also lower cost than conventional lighting. Whilst the capital cost of the lights is higher than conventional streetlights, they can be spaced more widely, leading to fewer units. Due to the lower energy consumption running costs are significantly lower, and due to the longer bulb lifetime maintenance costs are lower.

In a 2011 trial by Philips LED lights were installed on 7km of busy highway (A44) near Amsterdam. The pole height was 12m and the spacing was 56m. The lights could also be dimmed to adjust for the time of day, weather conditions, and for emergencies, further reducing energy consumption. This is expected to save 40% of the energy consumed on this stretch of highway with a saving of 180,000 kWh per year, equivalent to the energy consumption of 50 households [2].

SOLAR POWERED LED LIGHTING

Solar powered LED roadway lighting is relatively new, although there are some examples on the market (e.g. Philips Luminaries). Solar powered LED roadway lighting is generally lower power and brightness than standard LED roadway lighting. The highest power solar powered LED lighting designed for roads has a rating of 100W, which for an efficiency of 100 lumens/watt gives 10,000 Lumens [10]. This is comparable to a conventional metal halide light (used for urban street lamps [11]), but lower than most LED systems designed for highway use.

According to DOT regulations, lighting must be independently powered. This means that the solar powered lights either have to be connected to the grid, which increases installation costs, or they need to have large back up batteries. Currently the best batteries available as part of a solar powered LED streetlight provide 5 days of backup power [12]. These are also somewhat unsightly as they are usually placed near the top of the light pole to prevent vandalism in urban environments. On an overpass or bridge it might be possible to site the batteries at the base of the pole for better aesthetics.

Source: http://www.myledlightingguide.com/article.aspx?articleid=38

Due to the lower lumen ratings, these lights are likely only suitable for areas where it is feasible to space the light poles relatively close together – overpasses or bridges.

COST ESTIMATE FOR LED LIGHTING

For a high-powered (100W) LED the installation cost for a 10km highway with 2 lanes and LED lights on both sides of the road with a pole distance of 30m would be [1]:

Grid connected LEDs: $22 million
Solar powered LEDs: $26 million
Conventional mercury lamps: $18 million

Adaptive sensors cost an average of $50 per light extra [2].

However, LEDs use 70% less energy to produce light than the standard mercury lamps, reducing the cost for power (in the non-solar powered case). There are also cost savings in the electrical transmission line because smaller copper wire and shorter line length can be used. The estimated payback time for the extra cost of installation for standard LEDs is 2.2 years and 3.3 years for solar powered LEDs [1].

DOT REQUIREMENTS FOR LED LIGHTING

DOTs tend to require the following technical specifications for LED lighting [38].

Area	Requirement	Notes
Operating temperature range	-40•C to +50•C (-40•F to 122•F)	
Power Supply	Have an integrated power supply	This may be an issue for Solar LED technology
Lifetime	Have a life rating of 100,000 hours or greater	
Delivered lumens	No more than 15% reduction in lumen output due to operating temperature. Deliver 80% of initial delivered lumens after 100,000 hours of operation.	Indicates failure mode for LEDs must be dimming rather than extinguishing.
Efficiency	Minimum efficiency of 70 lumens/Watt	
Color	Colour temperature from 3710-4260 K. Color Rendering Index (CRI) >60	
Light distribution	Pattern at road surface is to have an evenly disperse appearance.	

LEP LIGHTING

LEP (Light Emitting Plasma) lighting uses solid-state electronics similar to an LED. However rather than using the solid state device itself for light (as an LED does) the LEP light uses the solid state device to generate RF (radio frequency) energy that powers a plasma (ionized gas) emitter. This gives higher brightness and fuller spectrum light than most LEDs [3].

LEPs have many features in common with LEDs: reliability, directionality and focus of light output, and the ability to dim instantaneously. LEPs have an order of magnitude higher lumen density (amount of light from one device). That means LEPs are best suited for high luminance applications (replacing >250W standard lighting) such as high mast lights, whereas LEDs work better for low and mid luminance (replacing <250W standard lighting) [3].

LEP lights are more efficient than standard sodium lights but less efficient than LEDs. Energy savings are about 30-50% compared to conventional sodium or mercury lighting. Maintenance costs are also lower due to an increased lamp lifetime (up to 300% longer) [4]. These lamps are full spectrum (whiter than sodium or mercury). They are also small in size: a single LEP source a few mm in diameter can produce up to 10,000 lumens and replace multiple standard bulbs.

Like LEDs, LEPs inherently emit all of the light in a forward direction, which reduces the need for lenses and reflectors to achieve the required glare cutoff and illumination pattern. This can improve fixture efficiency vs. standard lighting by 30-50% [5,6].

Commercially available LEPs are rated for up to 50,00 hours in general lighting applications. In comparison a typical 400W metal halide lamp can last 12,000-18,000 hours [4]. This leads to reduced maintenance costs for LEP lights. They also take 45 seconds to reach full brightness when turned on compared to up to 10 minutes for standard metal halide lights.

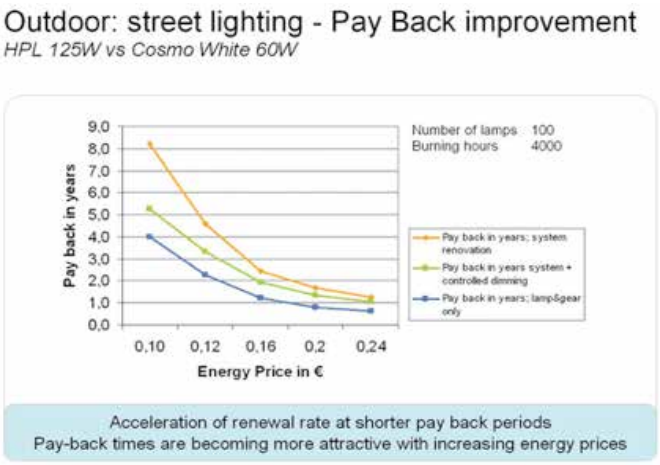
COST ESTIMATE FOR LEP LIGHTING

If LEPs replace standard lights on a 1-1 basis, they offer a 40% energy saving (where there is no dimming). Assuming an electricity cost of $0.08 per kWh this can lead to savings of $109 per year per light, based on power savings only [6]. This does not take into account the higher initial capital cost of the lamps. Over the lifetime of the lights there are also likely to be savings from reduced maintenance due to longer bulb lifetime, but the magnitude of this is hard to establish due to the lack of long-term trials. Manufacturers estimate a reduction in maintenance costs of 50%, but their lifetime ratings appear to be overestimated based on results of current trials.

INTELLIGENT CONTROL

Many LED and LEP lighting options include intelligent control of light levels. This includes the ability to automatically dim the lights in response to ambient light conditions, the time of day or any other factor (e.g. the cycle of the moon). They can also be networked and remotely controlled, either by sending the data over the power lines, or wirelessly [6].

Source: http://www.luxim.com/products/high-mast-lighting



Source: https://www.rtcc.org/2009/html/help-consumers-1.html

These allow users to control fixtures by group or individually in real time. Automatic lighting schedules can be created to turn on, dim or turn off fixtures at predetermined times or situations. Network control can also be used for diagnostics or to enable predictive maintenance.

Remotely controlled LED lights could be switched off, or dimmed, in response to a wide range of factors.

Source: http://www.gizmag.com/smart-highway-glowing-lines/34363/

SMART ROAD LIGHTING – DYNAMIC SIGNAGE AND ROAD MARKINGS

A broad range of lighting technologies have been deployed or trialed to make roads safer.

Solar charged glowing paint is being used for road markings in a trial by Heijmans in the Netherlands [36]. The paint absorbs energy from the sun during the day and then glows for up to 10 hours when it gets dark, improving the visibility of road markings without using additional electricity. The same trial is also investigating temperature sensitive paint that could become visible in cold temperatures to warn drivers about ice. The trial also includes interactive lights that seek to detect where cars are on a road and then light only the sections of the road around and in front of them [37].

LED variable message signs are low energy and can be used to provide drivers with changing information. For example, these could be used to display speed limits that adjust for different times of day, warn of traffic hazards or allow dynamic lane control signals [38, 39].

Source: http://www.standardsforhighways.co.uk/ha/standards/tech_info/files/MM-ALR_Concept_of_Operations_v2_0.pdf

Companies such as Swartco [40] and SES America [41] and have produced such signs which are currently used for smart traffic management on the UK motorways [39].

LED reflectors can be used for dynamic lane markings, and companies such as Reflecto [36] and Sernis [36] build custom systems using these. Both these companies appear to have substantial R&D efforts in addition to their off-the-shelf products and may be willing to consider partnerships to demonstrate the potential of their technologies. Rennicks, [44], a UK based company, have provided solar powered active LED studs to the Highways Agency for trials on various sections of UK motorways [45,46].

Intelligent road studs (IRS) have been used as a fog warning system in Scotland, changing color to warn road users of the weather hazard [48]. Algorithms are used to determine the type and extent of alert required, before control units automatically relay instructions to appropriate strings of IRS which in turn flash a warning to approaching traffic or increase in brightness to aid visibility. Intelligent queue tracking of cars allows only the strings of studs upstream of any slow moving or stationary traffic to be activated [48]. These road studs were developed by Astucia who have a range of IRS products [49].

Source: http://www.clearviewtraffic.com/images/products/22-solarlite-f-series-flush-road-studs_specsheet.pdf

Unipart Dorman have developed lights that are mounted on top of traffic cones [37]. These are used when a taper of cones is used to close a lane, and the lights flash in sequence. The lights can be simply installed in any order, and the intelligent wireless network between the lights automatically determines the sequence. The lights have been shown to slow drivers down and prevent last second decisions and taper maneuvers.

Source: http://www.unipartdorman.com

POTENTIAL SUPPLIERS OF LED AND LEP LIGHTING

BRIGHT LIGHT SYSTEMS

Bright Light Systems is a Georgia based company that offers both LEP and LED technology, including optional connectivity and smart management technology [8]. Its current focus appears to be on LEP lighting for industrial sites, including ports, shipping terminal and airports. It recently installed an LEP system at the Port of Seattle [9] where it installed LEP luminaries on high mast lights (65ft) poles and achieved an energy saving of 50%, reducing CO2 emissions by 350 metric tons and estimated savings of $40k annually. The payback time for the project was estimated at 4.8 years. This is based on an estimated energy price of $0.08 per kWh and an assumed maintenance saving of 80% [9].

SOLAR STREET LIGHTS USA

Solar Lights USA is a Michigan based manufacturer of solar LED lights, including those for highways [10]. However, the current major application appears to be for urban or suburban street lighting, with the lights designed to be relatively closely spaced. The products currently on offer may not be bright enough to be able to replace overpass or bridge lighting on a one-to-one basis.

There are solar lights with the option of either grid power or battery storage. The GridSmart range incorporates the solar lights into the electrical grid. This means that if the lights cannot generate enough power, they can draw off the grid, and if they generate excess power they can sell it back to the grid rather than storing it locally [11]. The GridFree products that are self-contained solar lights have a battery large enough to store 5 days of power, but have a maximum wattage of 100W, which may require increased lamp density to match current brightness levels [12].

The LEDs in these lamps are Rebel LEDs made by Philips. SolarLight's expertise appears to be integration with the battery and solar panel technology.

PHILIPS

Philips offer LED street and road lighting, including solar powered lighting. However, their solar powered lighting are only rated to a maximum of 43W, with an efficiency of 100 lm/W, corresponding to a brightness of 4,300 lumens [13], compared to average brightness of 16,500 for a sodium lamp [14]. They also only have 2 days autonomy based on battery storage. Replacing any of the lights on The Ray with these would need a greater density of lights, which is likely to negate the energy savings of the LEDs vs. conventional lamps. It would also require significant trials to prove that the 2 days of autonomy provided give enough reliability.

IRIDIUM GEN 3

These LED street lamps are descripted as 'plug & play' by Philips which means that they offer tool free instillation. They have a system efficiency of up to 124 lm/W and brightness up to 4,00 lumens (36W) [15]. These are likely most suitable for urban or suburban areas where many lights are being installed and the saving on installation and maintenance time is most valuable [16].

SPEEDSTAR

Speedstar is Philips' top-of-the range LED street light, with powers up to 256W and fluxes up to 29,000 lumens [17,18]. It has efficiencies up to 104 lm/W,

and a color rendering index from 68-84 (cool to warm white). It lasts 70,000-100,000 hours and is dimmable. In UK trials on a two-lane highway, it offered energy savings of up to 70%, or 47 tons of CO2 per year [19]. Philips have also committed to making the production of this light carbon neutral (by purchasing carbon credits equal to the CO2 produced during manufacture) [20].

GE

GE LED street lighting solutions are mostly designed for urban and residential areas. The Evolve light is designed for local and collector roadways, with a design to maximize optical efficiency and minimize glare [21]. These have powers from 30-90 W, corresponding to brightness of 3100-8500 lumens [22]. This means they are likely only suitable for areas where lighting can be placed relatively densely or where lower levels of illumination are acceptable.

LUXIM

Luxim manufactures LEP lights for industrial and transport applications. A 280W LEP can produce 20,000 lumens at fixture, which can correspond to 12,800 lumens at road due to the forward direction of the light and low losses. For comparison, a sodium lamp with the same fixture lumens would only provide two-thirds of the road level brightness [23]. They appear to be the leading US provider of highway and industrial LEP lighting, especially tall pole lighting. They have been used at industrial sites including the Port of Seattle and the Pacific Gas and Electric Company [24].

STRAY LIGHT OPTICAL

Stray Light Optical are experts in fitting LEP solutions – they specialize in customizing LEP solutions made by other manufacturers (like Luxim) for different applications [25, 26].

LED ROADWAY LIGHTING

LED Roadway Lighting is a Canadian company that is focused on developing low cost LED street lighting solutions. They currently have two main product series, NXT and Satellite [27]. NXT luminaires are designed to be simple to install and replace without tools. Designed primarily for suburban areas and highways, they consumer powers of up to 160W with brightness of up to 17,000 lumens and efficiencies of 85-100 lumens/Watt [28]. The satellite range is designed for long lifetime and low maintenance and offers higher powers, up to 200W and 16,000 lumens with a 20 year photocell life [29]. These have been used to illuminate a bridge in Canada. In this project they achieved 70% energy savings with an estimated payback time of 3.5 years.

RECOMMENDATIONS FOR THE RAY

A sustainable highway must use the most efficient lighting technology to reduce carbon emissions and save costs. Advanced lighting, and specifically solar powered LED studs in the road, could also improve safety. We suggest these projects for The Ray.

REPLACE ALL MERCURY OR SODIUM LIGHTING ON THE RAY WITH THE LATEST LED AND LEP TECHNOLOGY

We suggest using LED lighting to replace all the standard (low mast) street lighting on The Ray, and LEP lighting for high illumination areas e.g. the tall lights on Exit 2. Given the lower running cost and potential for smart control it may also be beneficial to install LED lighting on areas that are not currently lit e.g. Exit 13 and 14 to improve safety of night driving.

To replace the tall lights on exits with LEPs, we recommend contacting Luxim [32] or Stray Light Solutions [33]. Luxim manufactures a range of LEPs and Stray Light Solutions has experience with integration for a variety of applications.

For the rest of the lighting on The Ray, for which lower luminance LEDs would be suitable, there are many options for suppliers. There are detailed recommendations for the assessment and implementation of LED/LEP lights in a report from the Indiana Department of Transportation and Purdue University. This specifies which products from which suppliers they chose to use for various highway applications after a year long trial [34].

PILOT SOLAR POWERED LED LIGHTS ON THE BRIDGE AT EXIT 6

For the bridge overpass at exit 6, currently the most brightly lit area on The Ray, we recommend using solar LED lighting with intelligent control. This will provide a test bed for the solar technology, to determine factors like the visibility of power storage and the optimum spacing, and allow the benefits of automated control such as dimming schedules to be demonstrated. This trial could then inform wider application of solar powered LED lights on the Georgia highway system. For intelligent control of the lights transmitting data through the power line is likely to be the best option, giving control of the lights without requiring wireless infrastructure.

We suggest contacting Solar Street Lights USA [31] as they have experience with custom design of solar powered LED solutions. The key parameters to optimize are whether these lights need to be integrated into the Grid or whether large and sufficiently reliable batteries can be installed to satisfy DOT power independence requirements. As these lights are lower brightness than other LED/LEP solutions, they will work best where there is the ability to have relatively high density lighting – overpasses and bridges.

TRIAL A SMART SYSTEM OF INTELLIGENT ROAD STUDS ON A SHORT STRETCH OF HIGHWAY

Solar powered LED intelligent road studs have been demonstrated in a number of locations. They illuminate the road lines much more clearly than basic reflectors, and improve safety. A few hours of sun can power the reflectors for a few days. However we think there's much more potential in this technology, and propose a road stud with:

- a solar panel
- a battery
- LED lights that can change color
- a proximity sensor to sense passing vehicles

• a vibration or contact sensor to sense when a vehicle drives over the stud

• a wireless mesh network for communication between studs

This would enable a broad range of possibilities.

The studs could:

• simply illuminate the lines at night improving visibility

• the lights between two cars could change color if they are driving too close together

• the lights ahead could flash rapidly if a car drives on the studs, giving a visual warning to a drifting driver before they hit the rumble strips (there appears to be a ~1 foot gap between the rumble strips and the white line on I-85)

• pulse gently at the speed limit to help drivers stick to the speed limit

• change color or flash to indicate a hazard or bad weather ahead

Although we have not seen any one company with all these features, a good partner for this might be Clear View Traffic, which has a range of intelligent road stud products (the Astucia range). Alternative partners might be Reflecto or Sernis. We have not seen a wireless network in a road stud – one partner for this might be Unipart Dorman [37], who have a similar system to make their traffic cone lights pulse in sequence.

1. Wu, M. S., et al. "Economic feasibility of solar-powered led roadway lighting." Renewable energy 34.8 (2009): 1934-1938.
2. http://www.ledsmagazine.com/articles/2011/02/philips-installs-led-lights-along-7-km-length-of-highway.html
3. http://www.luxim.com/technology/case-studies/41-lep-roadway-lighting-in-guangdong-china
4. http://www.luxim.com/technology/plasma-lighting-faq
5. http://www.reduser.net/forum/showthread.php?59154-Cutting-through-the-hype-surrounding-Light-Emitting-Plasma-%28LEP%29-lamps
6. http://straylightoptical.com/wp-content/uploads/2011/11/DEED-Final-Report-Draft-REVC.pdf
7. Li, Shuo, et al. Cost and Energy Efficient (LED, Induction and Plasma) Roadway Lighting. No. FHWA/IN/JTRP-2013/19. 2013. http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=3044&context=jtrp
8. http://www.brightlightsystems.com/company.html
9. http://www.brightlightsystems.com/resources/case-studies/Port-of-Seattle.pdf
10. http://solarstreetlightsusa.com
11. http://solarstreetlightsusa.com/our-lighting-products/gridsmart
12. http://solarstreetlightsusa.com/our-lighting-products/gridfree
13. http://www.lighting.philips.com/pwc_li/in_en/connect/assets/solar_street_lighting/Philips_Solar_Street_Light_Brochure.pdf
14. http://www.redcar-cleveland.gov.uk/Lighting.nsf/WebList/FC71F8919BBE38B680256CA80039F752?OpenDocument
15. http://download.p4c.philips.com/l4bt/4/416071/iridium_gen3_led_mini_416071_ffs_eng.pdf
16. http://www.lighting.philips.com/in_en/connect/tools_literature/downloadable-product-brochures/solar_street_lighting.wpd
17. http://www.lighting.philips.co.uk/prof/outdoor-luminaires/road-and-urban-lighting/road-and-urban-luminaires/speedstar
18. http://download.p4c.philips.com/l4bt/3/330540/speedstar_bgp321_330540_ffs_eng.pdf
19. http://www.lighting.philips.co.uk/cases/cases/road-and-street/a5-tamworth.html
20. http://www.ledsmagazine.com/articles/2011/03/philips-speedstar-road-lighting-led-luminaire-is-carbon-neutral.html
21. http://www.gelighting.com/LightingWeb/na/solutions/outdoor-lighting/street-roadway/evolve-led-streetlight-erl1.jsp
22. http://www.gelighting.com/LightingWeb/na/solutions/outdoor-lighting/street-roadway/evolve-led-streetlight-erl1.jsp
23. http://www.luxim.com/downloads/lep-brochure.pdf
24. http://www.etcc-ca.com/sites/default/files/reports/Light%20Emitting%20Plasma%20PG%26E%20SFP%202012%20ET%20Report.pdf
25. http://straylightoptical.com/news
26. http://straylightoptical.com/wp-content/uploads/2012/07/FM000027C-Specification-Sheet-Tesla-II.pdf
27. http://www.ledroadwaylighting.com/en/nxt-series.html
28. http://www.ledroadwaylighting.com/images/pdfs/en/LRL_NXT_Spec_Sheet_EN.pdf
29. http://www.ledroadwaylighting.com/images/pdfs/en/LRL_SAT_Spec_Sheet_EN.pdf
30. http://www.ledroadwaylighting.com/en/satellite-series.html
31. Solar Street Lights, 169 Manufacturers Drive, Holland, MI 49424

USA Phone: 616.399.6166 Email: http://solarstreetlightsusa.com/get-quote-contact-us
32. Luxim, LUMA America, 3542 Bassett St., Santa Clara, CA 95054, Telephone: (408) 734-1096, FAX: (408) 496-1192, Email: info@luxim.com
33. Stray Light, 821 S. Lake Road South · Scottsburg, IN 47170 , Telephone: (812) 752-9104
34. http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=3044&context=jtrp
35. http://www.reflecto.co.uk/welcome.html
36. http://www.sernis.com
37. http://www.unipartdorman.com/safety-initiatives/pdf/SynchroGUIDE%20-%20Changing%20the%20face%20of%20work%20zone%20safety%20(1).pdf
38. 2012 United States Department of Transport Federal Highway Administration Lighting Handbook. https://safety.fhwa.dot.gov/roadway_dept/night_visib/lighting_handbook/pdf/fhwa_handbook2012.pdf

FULLY SERVICED REST STOP

In the UK, motorway service areas are integrated sites where drivers can leave a motorway to refuel, recharge, use the restroom, eat, drink, shop and/or stay in a hotel. The sites are leased to operating companies, and currently the majority of service areas in the UK are run by three companies – Moto, Welcome Break and Roadchef. This has led to concerns that these companies have an oligopoly, and there have been complaints that the service areas are overpriced and often unclean.

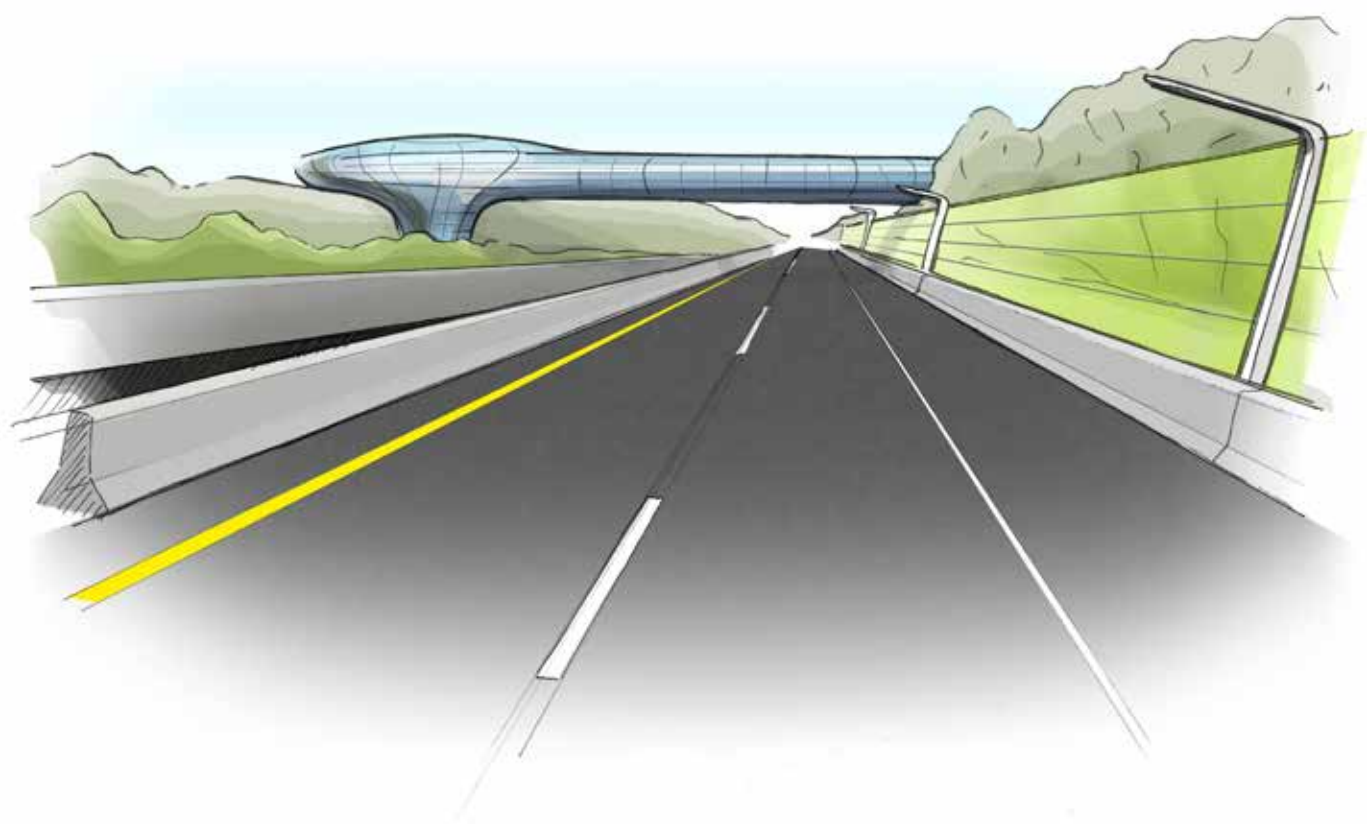
However we would argue that UK service areas have improved in recent years, and offer a quality, integrated and convenient experience. One recent trend has been the addition of up-market grocery stores from brands such as M&S and Waitrose. These allows motorists to buy quality ingredients, or a 'ready to cook' meal, for when they get home.

One company, Westmorland, operates on a different model. They started when local farmers, John and Barbara Dunning, set up a service area at Tebay when the M6 motorway was built (www.tebayservices.com). They avoid large brands or chains, partner with local bakers and producers, and sell only local and organic produce in the restaurant. They invoke a strong sense of place, have a local farm shop on site, and inform customers about their food. For example, they use meat from the whole animal in their cooking, minimizing food waste. Rather than being a stop of necessity, motorists will actively plan their journeys to stop at Tebay, as it's a genuinely pleasant experience. Westmorland have recently opened a new service area at Gloucester, with a striking 400m2 green roof (www.gloucesterservices.com).

The latest service station to open in the UK was Cobham services (http://www.extraservices.co.uk/location/cobham/). This follows the more traditional model of offering a selection of branded shops and food outlets, and is run by Extra MSA, the UK's fourth largest operator of service areas. The notable thing here is the sustainable drainage system. Retention basins, swales (marsh areas) and infiltration trenches help to clean water run off, and absorb harmful substances, before it is discharged into the local waterways.

"Tebay Services" by David Medcalf. Licensed under CC BY-SA 2.0 via Commons - https://commons.wikimedia.org/wiki/File:Tebay_Services.jpg#/media/File:Tebay_Services.jpg

"Gloucester Services" by Hogyn Lleol. Licensed under CC BY-SA 4.0 via Commons - https://commons.wikimedia.org/wiki/File:Gloucester_Services_(north).JPG



RECOMMENDATIONS FOR THE RAY

We recognize that a fully serviced rest stop, with direct access from the highway, is not currently allowed in the US, due to concerns about private companies profiting from a public service. However if this can be overcome, we believe there's potential to create a destination on The Ray that people will stop for. The experience should be, in this order:

1. Convenient – a single place where you can fill up with gas, get a coffee, eat a good (local?) meal, use a clean restroom, and perhaps buy some groceries

2. Pleasant – clean, attractive, great service, 'not just your average rest stop', perhaps a lake or forest trail for a short walk

3. Informative – allows you to learn something about sustainability and The Ray.

This could help to spread the message of The Ray, create a sense of place, offer a profitable business opportunity, and perhaps help to reinvigorate the economy of West Point.

VISION OF 2040

INTRODUCTION

The future is uncertain.

We can project today's trends out for ten years. We can investigate technology that is in development and make educated guesses about which will develop. However we can't predict the distant future with any certainty.

To prepare The Ray for 2040, we can instead consider different future visions for roads. What could the road of 2040 look like? Is The Ray's strategy able to adapt to succeed in different possible futures?

Here we present two possible approaches for making road transport more sustainable, safer and more efficient. These scenarios may be a result of differing economic, technological and climate factors that affect the nation, or they may simply be different approaches for heavily trafficked urban corridors or low-density rural highways.

SCENARIO 1 - FRUGAL INNOVATION

In this vision of the future, all the technology is in the vehicles and the road becomes relatively low-tech and minimalistic. Fully autonomous vehicles can travel unaided on any roadway and provide the best platform for sensors. Insurance companies have raised premiums for any car that is driven by a human, making autonomous vehicles almost universal. Fast chargers and high capacity batteries lead to electric vehicles dominating the roadway and the retirement of the internal combustion engine. Heads-up displays and onboard screens are the main medium for communication with road users.

In this world, the goal of the roadway is to reduce costs, achieving net zero by being as invisible as possible. Intelligent traffic management permits more efficient utilization of the roadway, reducing the need for roads to be built or expanded. Natural habitats are reclaimed as roads are narrowed. Public spending and carbon emissions are reduced as fewer road materials are needed along with less frequent maintenance. The pollution impact on the natural environment from noise and light is almost zero.

SCENARIO 2 - HIGH TECH CORRIDOR

In this vision of the future, there is mixed use of the road by autonomous vehicles, older retrofit vehicles, and human-driven cars. The reduced level of investment and ownership of personal transportation has slowed the replacement of the vehicle fleet. Gasoline-powered cars remain common and the joy of driving is a leisure activity that people wish to keep. Communication with road users occurs through smart signage on the road.

In this world, the goal of the roadway is to offer maximum value and the best experience to road users. The road is a source of revenue from personalized advertising and from contributing sensor data to intelligent infrastructure networks. This income provides investment in new road technologies that can achieve net zero. Networked fixed sensors are ubiquitous in the roadway, which also acts as the primary corridor for intercity data and clean energy distribution networks.

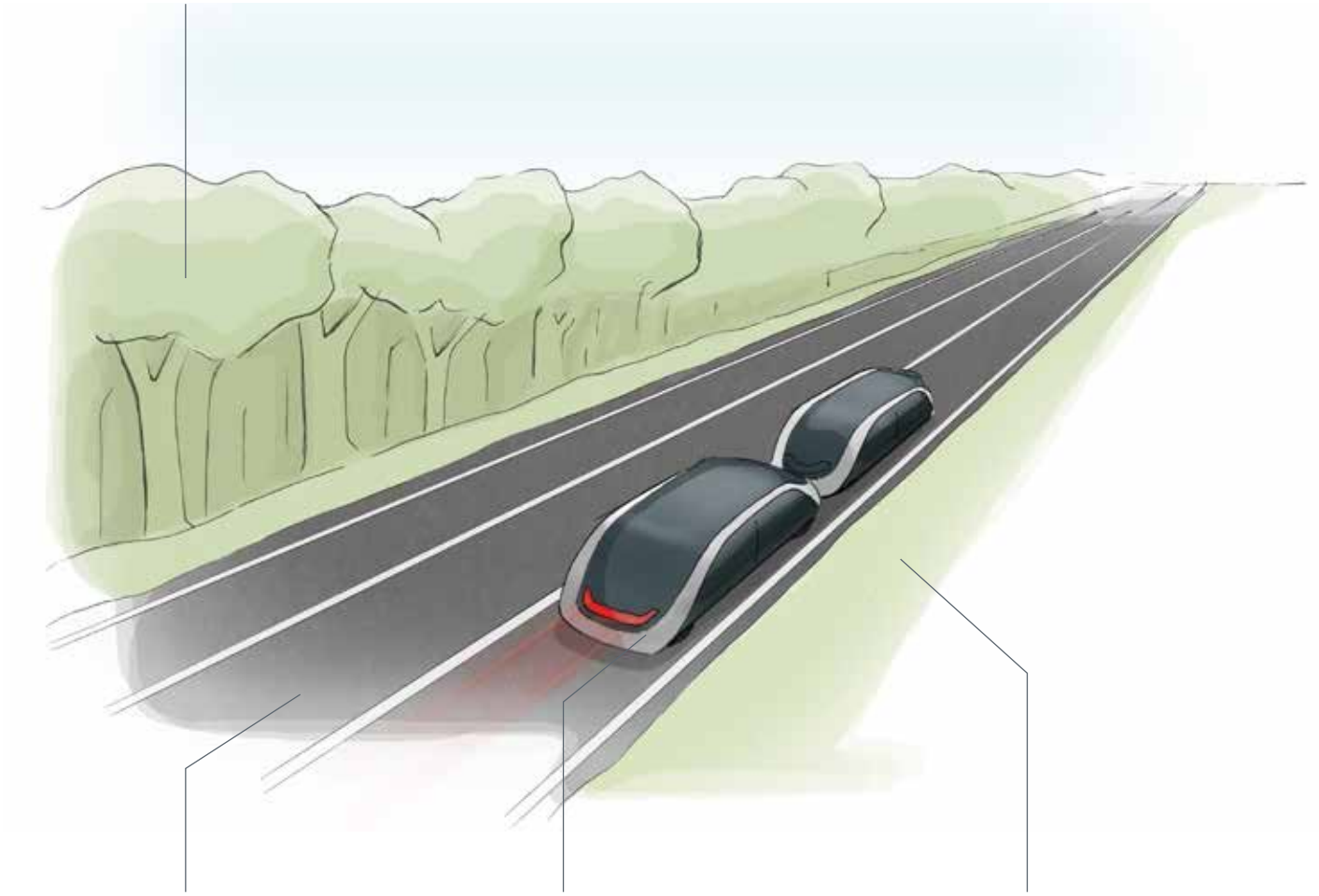
FRUGAL INNOVATION

ROADSIDE TREES

The shoulder, median and verge are all reforested, restoring the ecosystem and capturing carbon.

HIGHER AND ADAPTIVE SPEED LIMITS

Collaborative braking and active measurement of road conditions by autonomous vehicles allows them to travel at higher speeds where intercity vehicles have highest fuel economy.



NARROWER ROADS

Due to proven autonomous car safety and public acceptance, lanes are narrower. There is no need for a shoulder, median or verge. There may be a shared overtaking lane in the middle.

ROAD TRAINS

Freight and passenger traffic operates in road trains to improve aerodynamics. Sharing of fleet capacity between companies maximizes utilization.

NO LIGHTING

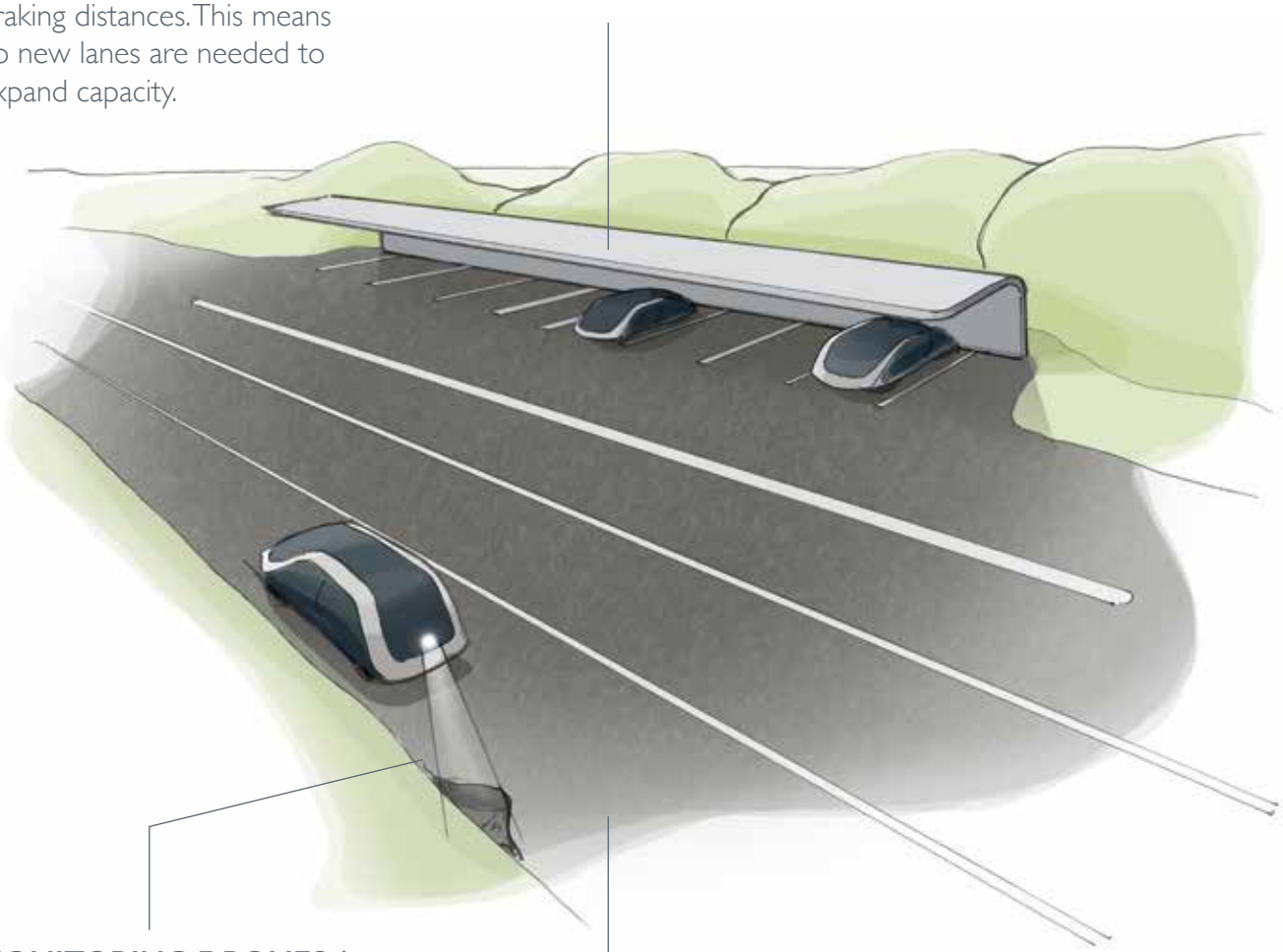
Due to infrared sensors and other proximity detection methods, there is no need for lighting on the road or on vehicles, eliminating light pollution. Deer and debris are detected and avoided by each car.

MORE CAPACITY FROM THE SAME ROADWAY

Roadway utilization is much higher due to autonomous vehicles needing shorter braking distances. This means no new lanes are needed to expand capacity.

ELECTRIC VEHICLE CHARGING TURNOUTS

Solar EV superchargers and hydrogen fueling points are found on turnouts at the roadside. Vehicles charge fast and travel far between charges, so a small number of chargers service a large number of vehicles.



MONITORING DRONES / EMERGENCY RESPONSE AND TELEHEALTH DRONES

The condition of the highway is monitored by drones, which also carry out repairs and maintenance tasks. Emergency drones provide assistance at incidents, although these are very rare.

SHALLOWER SUBBASE

A dedicated HGV lane is the only one with a deeper subbase - light vehicle lanes, and overtaking lanes are all much shallower.

RAPID FABRICATION AND REPAIR

Pre-fabricated carbon-negative concrete road slabs with rollable pre-fabricated paving radically reduce the cost of repairs.

HIGH TECH CORRIDOR

TOLLS AND VALUE ADDED SERVICES

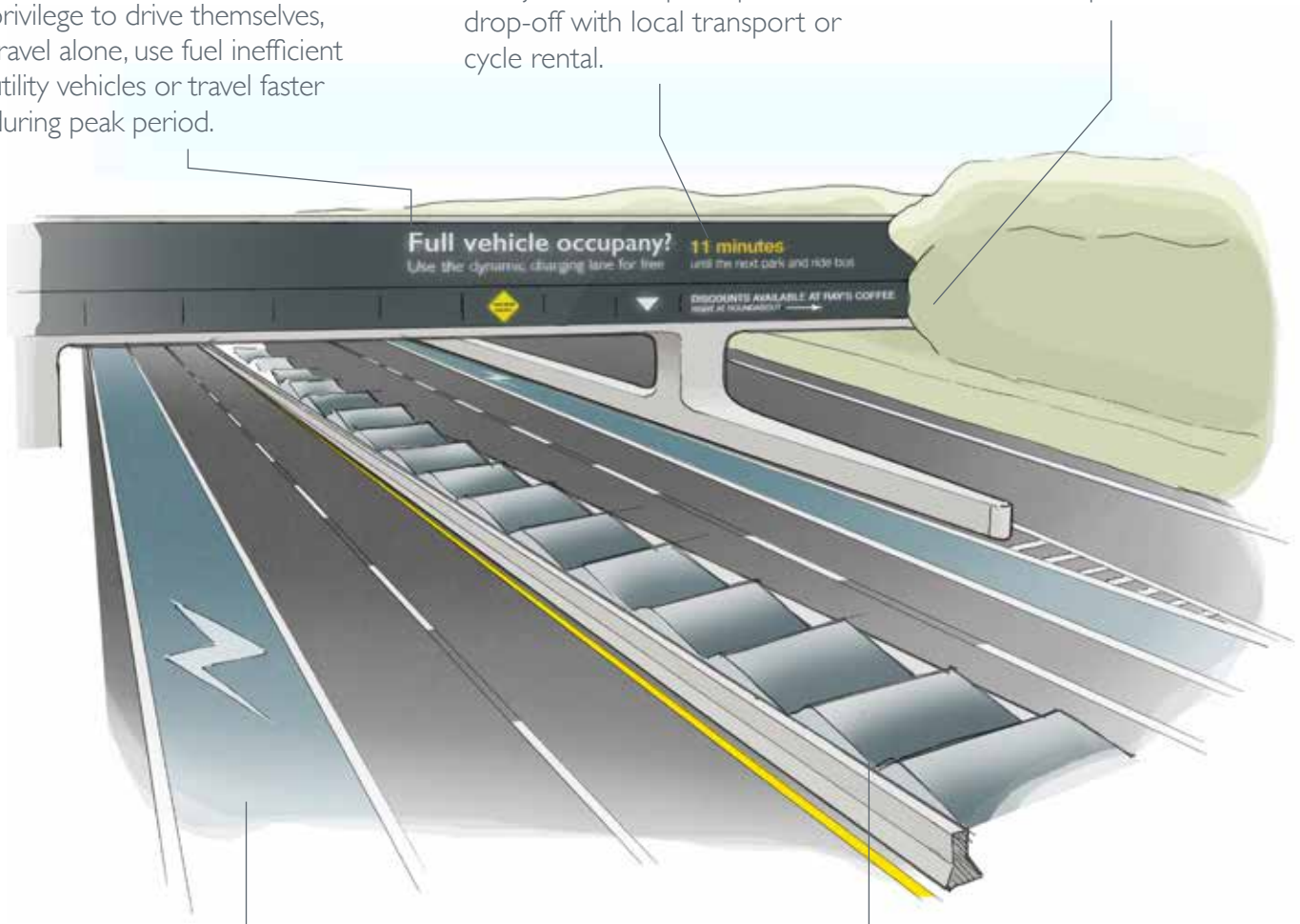
Roadway sensors charge tolls based precisely on road usage and environmental impact of the journey, paying for road maintenance and carbon credits directly. Road users pay for the privilege to drive themselves, travel alone, use fuel inefficient utility vehicles or travel faster during peak period.

INTERMODAL RIDE SHARING

Users are assisted in travelling seamlessly between modular public transport and private intercity ridesharing, using a single augmented reality app with just-in-time pick-up and drop-off with local transport or cycle rental.

PERSONALIZED ADVERTISING

Local services use smart billboards and vehicle recognition to serve targeted ads, providing additional income to the roadway. Consumer data is sold to companies.



DYNAMIC ELECTRIC VEHICLE CHARGING LANES

These lanes are coupled to solar farms on the road median.

HIGH VOLTAGE DIRECT CURRENT SUPERHIGHWAY

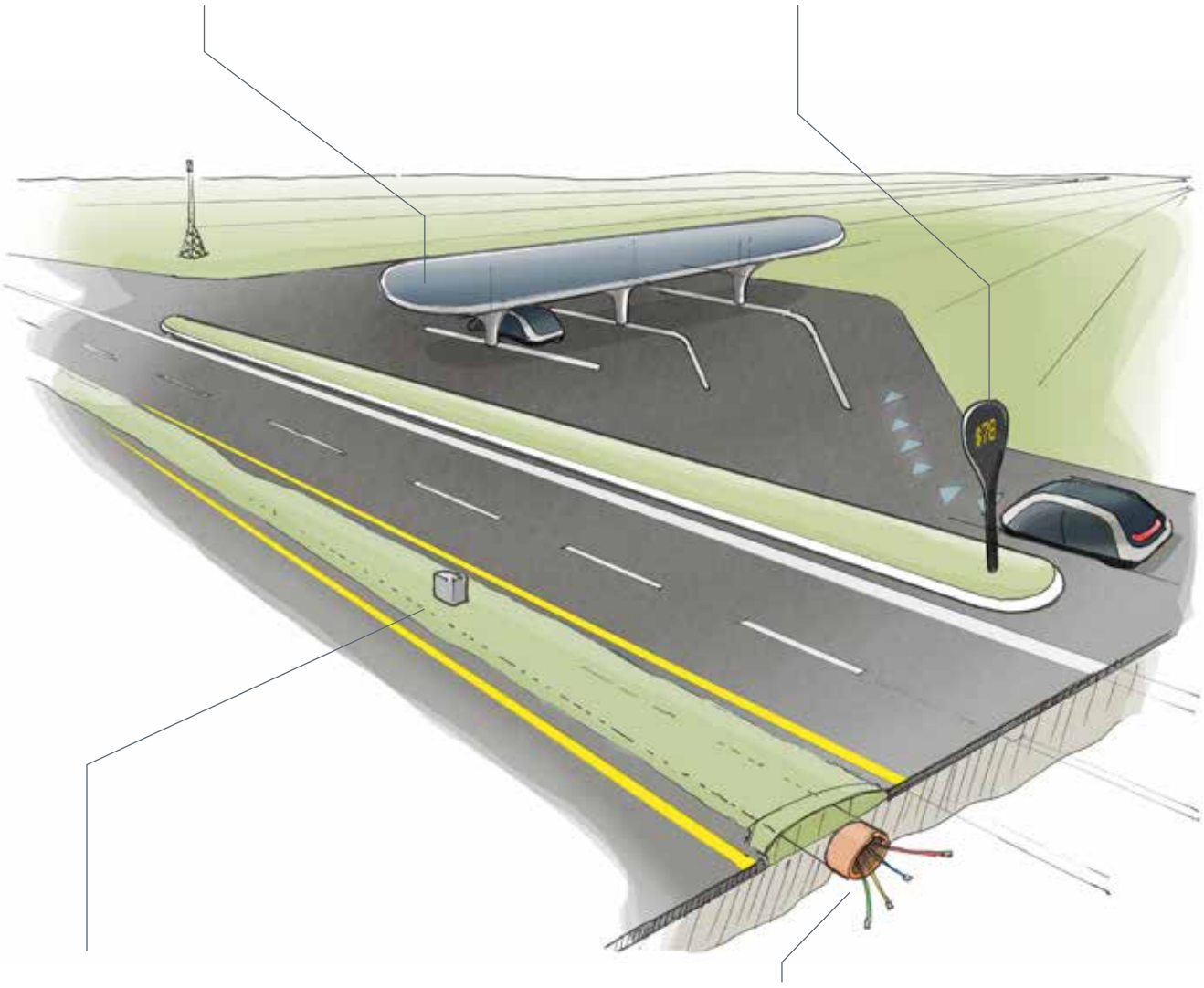
The roadway, solar panels and DEVC lanes are all part of a massive HVDC network connecting renewables with urban centers along the existing federal highway system.

ALGAL BIOFUEL STATIONS

Sourced from desertified land by the roadside, renewable fuel sources keep internal combustion engines carbon neutral.

DYNAMIC SIGNAGE

Vehicle specific information and directions can be provided through dynamic signage and road lighting.



SAFETY TRACK

Roadway sensors provide real-time data on self-drive vehicles and read driver intentions (creating space for lane changes and early warning for braking). Data predicts future congestion, adjusting speed limits and freight tolls to compensate.

DATA CONNECTIVITY

High bandwidth, low latency wireless data connectivity throughout the highway with fiber optic trunk lines running along the corridor.

APPENDIX: HIGHWAY INNOVATION AROUND THE WORLD

Highways around the world are changing. Governments, companies and the public are realising that our roads must evolve to meet the needs of the future, and the pace of innovation is rapid.

We present below a broad range of innovative projects and technologies, many of which could play a part in the sustainable road of the future.

BIOFUELS

CARBON CAPTURE

CONSTRUCTION MATERIALS AND PROCESSES

ELECTRIC VEHICLES

IMPROVING FUEL EFFICIENCY OF ICE CARS

LIGHTING

LOW CARBON CONCRETE

NOISE REDUCTION

RENEWABLE ENERGY AND ENERGY HARVESTING

SAFETY

SENSING AND SMART HIGHWAYS

TRAFFIC MONITORING AND MANAGEMENT

WASTE MANAGEMENT

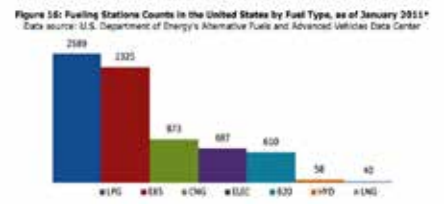
WATER MANAGEMENT

WILDLIFE AND VEGETATION

REPORTS, TRIALS AND PROJECTS

BIOFUELS

ALTERNATIVE FUEL FACILITIES



DOT

Stations that could deliver one or more of the following fuels would need to be installed:
Electricity, preferably from renewable sources;
Biofuels, primarily ethanol and biodiesel;
Propane or natural gas;
Hydrogen

http://www.fhwa.dot.gov/real_estate/publications/alternative_uses_of_highway_right-of-way/rep03.cfm

FREEWAYS TO FUEL

Freeways to Fuel

This is a national alliance designed to investigate the production of biofuels and food crops on non-agricultural land e.g. ROWs, military bases and airports. It has run pilots with crops planted on the Right of Way in Utah and North Carolina.

http://cawb.info/files/uconowner.pdf

ROADSIDE ALGAL INSTALLATION

Cloud collective

This is a conceptual demonstrator for converting vehicle CO2 emissions into algal fuel. It is prepared by a design firm, so the engineering and scalability issues are not addressed, but it is visible and marketable. In reality, an algal farm would need to cover a much larger area, and locating it near a highway would not have a significant benefit.

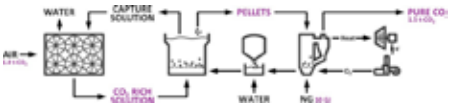
http://www.iflscience.com/environment/urban-algae-farm-gobbles-highway-air-pollution

CARBON CAPTURE

AIR CAPTURE OF CO2 - CARBON ENGINEERING

Carbon Engineering is a Canadian company that claims to be able to capture CO2 from air, with the aim of using it to enhance oil recovery or for geological sequestration. It uses lots of compression and capture via a precipitating sodium hydroxide solution.

http://carbonengineering.com/publications/



Carbon engineering

AIR CAPTURE OF CO2 - GLOBAL THERMOSTAT

Global Thermostat, a start up led by Columbia physics professor Peter Eisenberg has proposed using mines to capture CO2 from the atmosphere with a lower Regen temperature at 85°C enabled by solid format - 640 ceramic cubes embedded with the amine sorbent.

http://www.technologyreview.com/featuredstory/531346/can-sucking-co2-out-of-the-atmosphere-really-work/

Global thermostat

BLUE PLANET

Blue Planet has developed a way of sequestering carbon in concrete. Blue Planet uses flue gas derived CO2 to obtain building aggregates including concrete. Osmosis is used as a driver to produce alkaline solutions, which reduce parasitic load by up to 60% and CAPEX and OPEX by about 40%. The alkaline solutions are combined with liquid condensed droplets containing CO2 to concentrate the droplets and soften the waste water.

http://www.blueplanet-ltd.com/#sustainability

Blue planet

ECOLOGICIEL

ECOLOGICIEL is a Carbon Footprint® type software developed by Colas for proposing alternative solutions to clients. It allowed for a 15,000-metric ton reduction in equivalent in CO2 emissions in 2008. It helps with CO2 emission management and mitigation.

http://www.irfnet.ch/files-upload/pdf-files/IRF_BP_Environment_Web.pdf Colas

ROADSIDE CARBON CAPTURE AND STORAGE POTENTIAL

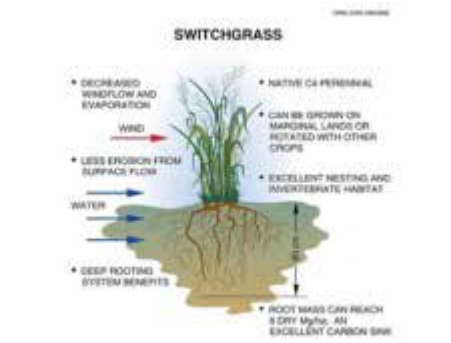
Deciduous broadleaf forests had the highest carbon uptake rates at 0.9 metric tons C/acre/year, compared to 0.4 C/acre/year for grasslands based on the measurements of the flux towers (Table 3).

http://www.montana.edu/spowell/FLMA%20Roadside%20Carbon%20Report%20Final_January2014.pdf

SWITCHGRASS FOR CARBON SEQUESTRATION

Switchgrass (Panicum Virgatum) is a prairie grass with a long root system that can sequester up to 5 tons of CO2 per acre. It is being used in Kansas along highways to absorb CO2 emissions from traffic.

http://www.kansas.com/news/article1093206.html



Oak ridge national laboratory

CONSTRUCTION MATERIALS AND PROCESSES

100% RECYCLED ASPHALT PAVEMENTS

Produce new pavements entirely from reclaimed asphalt with the use of existing asphalt plants and rejuvenators – materials that can restore the reclaimed asphalt properties for another life cycle. Research has been carried out to screen eleven different rejuvenators. At least four of these can provide properties of 100% recycled asphalt pavement that are equal or better compared to virgin mixtures.

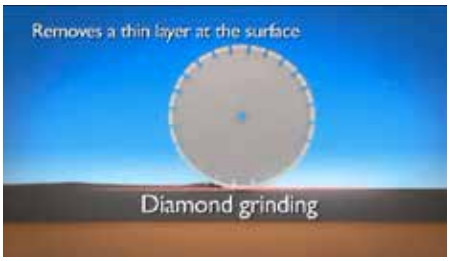
http://contest.techbriefs.com/2013/entries/sustainable-technologies/3784

Paving Atlanta

DIAMOND GRINDING

A quick and efficient way to remove road surface irregularities and thus provide a smooth surface without affecting the traffic.

https://www.youtube.com/watch?v=25wS0RihiJk



Roads&Traffic Authority (Australia)

ENVIRONMENTAL-FRIENDLY ROAD MARKING PRODUCTS

Ostrea Route and Ostrea Spray replace the use of quarry lime, eliminating the need for extraction and much of the raw material transport. Water-based road paints such as Typhon show 88% lower VOC emissions especially during the application phase than a typical solvent-based paint. PROSIGN G400 airless line marker, compared to other machines, shows superior operator safety and centralised control station management.

http://www.irfnet.ch/files-upload/pdf-files/IRF_BP_Environment_Web.pdf

Aximum

FOREVER OPEN ROAD-ADAPTIVE

The adaptive road will provide a quick and cost effective method of designing, constructing and maintaining roads. This can be achieved by using pre-fabricated modular units with built-in communication, drainage and utility channels. Severely damaged modular units can be replaced easily.

http://perso.lcpc.fr/hautiere.nicolas/pdf/2011/hautiere-piarc11.pdf

TRL

FULL DEPTH RECYCLING

Full depth recycling or full depth reclamation (FDR), is a process that rebuilds worn out asphalt pavements by recycling the existing roadway. A reclaimer lifts up and pulverises the old asphalt base. Another machine then mixes it with a rejuvenator and lays it back down on the road.

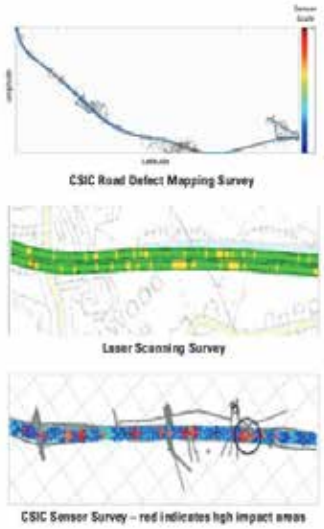
"Full depth recycling screenshot". Licensed under CC BY-SA 3.0 via Wikipedia - https://en.wikipedia.org/wiki/File:Full_depth_recycling_screenshot.jpg#/media/File:Full_depth_recycling_screenshot.jpg

"Full depth recycling screenshot". Wikipedia

GEOSPATIAL MAPPING OF ROAD SURFACES

This road mapping system uses sensors to measure road height changes and produces a map of sharp changes in height. It takes 2 people less than half a day to map an 18-mile section of a 3-lane road, and is more accurate than existing laser-based technologies. No disruption to traffic is required.

http://www-smartinfrastructure.eng.cam.ac.uk/what-we-do-and-why/focus-areas/sensor-data-collection/projects-and-deployments-case-studies/road-mapping-sensors



University of Cambridge

INDUCTION HEALING OF POROUS ASPHALT

A new ZOAB (porous asphalt) mixture in which steel fibres are mixed in the bitumen binder. This allows an in-situ rejuvenating heat treatment of the road surface by means of induction due to the electrical conductivity. This allows the wider use of porous asphalt, which is quieter.

http://perso.lcpc.fr/hautiere.nicolas/pdf/2011/hautiere-piarc11.pdf

Heijimans

MODIESLAB

A prefabricated road slab manufactured from concrete elements. The slabs can be constructed with channels for utilities connections and water run-off, and the open concrete surface has been designed to have low noise characteristics and low rolling resistance.

http://perso.lcpc.fr/hautiere.nicolas/pdf/2011/hautiere-piarc11.pdf

Modlieslab

NEW ASPHALT MIXING AND COMPACTION TECHNOLOGIES

The first technology lowers the maximum temperature of the asphalt during production and mixing can reduce fuel consumption at the mixing plants and asphalt smoke. Another technology enables the operator of a roller to choose the vibration mode of the compaction machine to prevent over-compaction and reduce energy consumption.

http://www.irfnet.ch/files-upload/pdf-files/IRF_BP_Environment_Web.pdf

Ammann

PLASTIC ROAD

Highways made of recycled plastic bottles. Plastic is assumed to be a greener alternative to asphalt that is stronger, easier to maintain, and more resistant to temperature extremes than conventional blacktop. This has not been demonstrated.

http://www.wired.com/2015/07/future-highways-made-recycled-plastic-bottles/

Volker-Wessels

POTHOLE FIXING MACHINE

The machine has a robotic arm which extends from the cab over the pothole and can take just 2 minutes to fill in a pothole – 30 times faster than traditional approaches.

http://www.paconsulting.com/our-thinking/driving-innovation-in-the-roads-sector/#here

Geoff Robinson

ROAD ON A ROLL

A prefabricated asphalt mat, approximately 30 mm thick, that is laid on top of an existing pavement with sufficient structural strength to carry the design traffic. Allows for faster repairs and low noise surface.

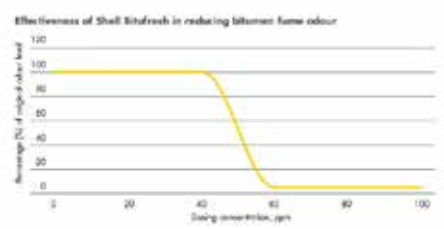
http://perso.lcpc.fr/hautiere.nicolas/pdf/2011/hautiere-piarc11.pdf

Road on a Roll

SHELL BITUFRESH

This is a bitumen additive that has been specially formulated to reduce the odour of bitumen, improving conditions for both workers and local residents.

http://www.shell.com/global/products-services/solutions-for-businesses/bitumen/products/shell-bitufresh.html#textwithimage_3



Shell

TERMINAL BLEND TIRE RUBBER ASPHALT (TBTRA)

The city of Colorado Springs experimented with a new pavement method, Terminal Blend Tire Rubber Asphalt (TBTRA), on select roadways to not only create quieter and safer driving conditions, but also to provide the most durable surface. It is also safer during rainstorms.

http://www.irfnet.ch/files-upload/pdf-files/IRF_BP_Environment_Web.pdf

The City of Colorado Springs

THE CATERPILLAR D7E TRACTOR

This is a new bulldozer with electric drive that increases dozing efficiency by 25% , lowers operating costs by 10% and reduces fuel consumption by 10 to 30%. The grade control system, which uses either laser or GPS signals, results in additional 30% improvement in the time to complete a job.

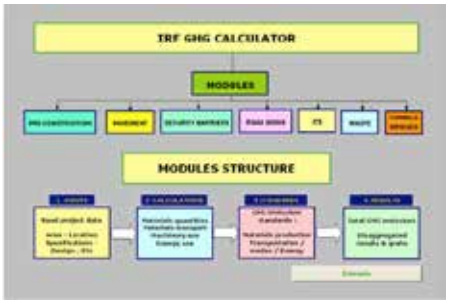
http://www.irfnet.ch/files-upload/pdf-files/IRF_BP_Environment_Web.pdf

Caterpillar Inc.

THE IRF GREENHOUSE GAS CALCULATOR

This provides a methodology for the calculation and modelling of carbon emissions for road construction and maintenance projects.

http://www.irfnet.ch/files-upload/pdf-files/IRF_BP_Environment_Web.pdf

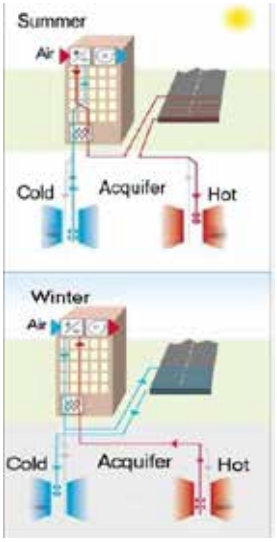


International Road Federation

THERMAL ENERGY ASPHALT PAVEMENTS

This uses an asphalt collector (a heat exchanger design incorporating tubes in the asphalt pavement) to extract heat from asphalt pavement and store it in an aquifer for seasonal supply and demand. Heat stored during the summer is used to melt snow in the winter.

http://www.irfnet.ch/files-upload/pdf-files/IRF_BP_Environment_Web.pdf



Ooms International

USE PLASTIC WASTE TO MAKE ROADS

An Indian scientist succeeded in using plastic for road construction which results in a more water resistant and flexible road. Plastic waste collected will be shredded and blended with pre-heated bitumen to form a mixture for road construction.

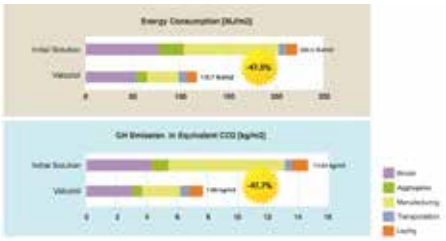
http://www.slideshare.net/HarleenSing/innovations-in-roads

KK plastic waste management pvt. Ltd

VALORCOL

VALORCOL is a cold asphalt concrete, based entirely on reclaimed asphalt aggregate. It uses mainly reclaimed asphalt, saving natural resources of gravel and stones. The binder used is a cold asphalt emulsion, so there is no need for heat during preparation and mixing, resulting in energy and CO2 savings.

http://www.irfnet.ch/files-upload/pdf-files/IRF_BP_Environment_Web.pdf



COLAS

VEGECOL, VEGEFLUX, 3E ASPHALT MIX

VEGECOL is a translucent colorable plant-based binder made of renewable plant products, as a substitute for bitumen> It allows for production of asphalt mixes at temperatures that are 40°C lower than conventional mixes. VEGEFLUX is a flux agent containing plant-based raw materials and emits no volatile organic compounds. 3E asphalt mix is manufactured at lower temperatures than conventional mixes.

http://www.irfnet.ch/files-upload/pdf-files/IRF_BP_Environment_Web.pdf

Colas

ELECTRIC VEHICLES

AUTOMATED EV CHARGING STATION

VW and Tesla are both developing fully automated robotic charging stations that simply require an EV to park alongside it.

http://www.vwvortex.com/news/volkswagen-news/e-smartconnect-volkswagen-conducting-research-on-automated-quick-charging-system-for-next-generation-electric-vehicles/

Volkswagen

AUTONOMOUS EV CHARGING ROBOT

Autonomous roaming EV chargers that use recycled Nissan EV batteries do not need fixed infrastructure in each parking spot.

http://www.wired.com/2015/07/rolling-battery-fixes-ev-chargings-big-problems/

Freewire Technologies

ON-LINE ELECTRIC VEHICLE (OLEV) CHARGING

Electric vehicles pick up power from cables buried underground via a non-contact magnetic charging method, with a 13 cm air gap between the road and the bottom of the vehicle. The technology has been trialed by the Korean Advanced Technology Centre.

http://perso.lcpc.fr/hautiere.nicolas/pdf/2011/hautiere-piarc11.pdf

Group 4 (OLEV)

SIEMENS E-HIGHWAY

Hybrid trucks use an active partograph to collect current from an overhead cable on a two mile stretch of highway. The project involves Siemens, Volvo and Transpower.

http://www.siemens.com/innovation/en/home/pictures-of-the-future/mobility-and-motors/electromobility-ehighway.html

Siemans

VEHICLE TO GRID OPERATIONS

Using vehicles parked overnight at a solar EV/PHEV charging point for load levelling on a renewables powered grid. Discharging of vehicle batteries to the grid is monitored to subsidise parking fees or simply credit the account of the user. (FastNed, Tesla, GM Onstar/TimberRock).

http://www.zerauto.nl/wp-content/uploads/2012/12/Electric_vehicle_smart_charging_and_vehicle-to-grid_operation.pdf

FastNed

IMPROVING FUEL EFFICIENCY OF ICE CARS

HONEYWELL TRANSPORTATION SYSTEMS

This provides turbocharger technology for passenger and commercial vehicles.

http://www.honeywellnow.com/2015/07/02/get-the-best-gas-mileage-out-of-your-car-during-your-next-summer-road-trip/

Honeywell

MICHELIN FLEET SOLUTIONS

Michelin Fleet Solutions offers large truck fleets all-inclusive tire management services: instead of buying tires, customers purchase travel mileage. Tire performance is optimized, thereby cutting fuel consumption. There are also fewer end-of-life tires that need to be recovered, thus reducing energy use and other disposal costs.

http://www.irfnet.ch/files-upload/pdf-files/IRF_BP_Environment_Web.pdf

Michelin

LIGHTING

BRIGHT LIGHT SYSTEMS

Bright Light Systems sell LEP and LED lights, including smart lights with management systems and controllable dimming. They have carried out projects for industrial locations and highways.

http://www.brightlightsystems.com/products.html

Bright Light Systems

CAT'S EYES

A cat's eye is a retroreflective safety device used to mark lanes in roads. It is made of two pairs of reflective glass spheres set into a white rubber dome, mounted in a cast iron housing. These are widespread in the UK but not elsewhere.

https://en.wikipedia.org/wiki/Cat's_eye_%28road%29

ELIOT2000

CLEARVIEW TRAFFIC ROAD STUD

These are smart, safe and sustainable surface mounted road stud, that are proven to increase night time road safety. They provide a view of the road layout ahead, in the drivers' natural line of vision, well beyond the headlight beam of a vehicle.

http://www.clearviewtraffic.com/astucia/products-astucia/art/26/solarlite-s-series-surface-studs.htm

Clearview

GREEN LIGHT BIKE PATH

The green lights help cyclists avoid red traffic lights. It is part of a growing wireless sensory network which serve functions like alerting the sanitation department to empty the trash cans and informing bikers of the quietest or fastest route to their destinations. Truck drivers can see on smartphones when the next light will change and then adjust their driving speed accordingly.

http://www.nytimes.com/2014/12/09/business/energy-environment/copenhagen-lighting-the-way-to-greener-more-efficient-cities.html?_r=0

Sofie Amalie Klougart for
The New York Times

LED STREET LIGHTS IN LOS ANGELES

Philips is supplying 110,000 LED street lights in Los Angeles. These are smart plug and play CityTouch lights that are quick to install and allow monitoring and control via the internet.

http://www.gizmag.com/philips-led-lighting-citytouch-los-angeles/36906/?%20utm_source=Gizmag+Subscribers&utm_campaign=109a73488d-UA-2235360-4&utm_medium=email&utm_term=0_65b67362bd-%20109a73488d-91575021

REJUVENATING LED LIT INTERCHANGES

These light the interchanges with LEDs. The light is designed to maintain drivers' night vision, wake them up, add interest, minimise light pollution and be good for local wildlife.

http://therushwoodgroup.com/photo-gallery/

The Rushwood Group

SOLAR LIGHTS USA

Solar Lights USA is a Michigan based manufacturer of solar LED lights for streets and roadways.

http://www.solarstreetlightsusa.com/

Solar Lights USA

SOLAR REFLECTOR

A British company developed a road stud that contains small solar panels to power LED lights in the stud at night

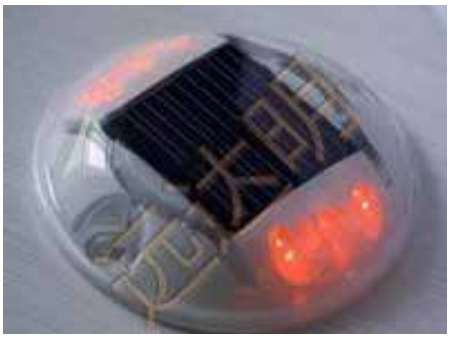
http://www.fhwa.dot.gov/real_estate/publications/alternative_uses_of_highway_right-of-way/rep03.cfm#sec3.1

WSDOT

SOLAR ROAD STUD

Solar road studs are flashing solar cell powered LED maintenance-free lighting devices used in road construction to delineate road edges and centrelines. Essentially electronic cats eyes, and brighter than conventional cats eyes.

https://en.wikipedia.org/wiki/Solar_road_stud



Austucia

SYNCHROGUIDE SEQUENTIAL LIGHTS

These are lights on cones that can communicate with each other so they pulse in sequence. This helps show drivers where two lanes are merging.

http://www.unipartdorman.com/product-solutions/SynchroGUIDE/SynchroGUIDE.aspx

Unipart Dorman

LOW CARBON CONCRETE

CALERA

Carbon dioxide is captured directly from raw flue gas and converted into a calcium carbonate cement system based on vaterite. Upon addition of water the vaterite recrystallizes as aragonite (shell material). Capture of CO2 in an alkaline calcium solution is dependent on a prior electrolysis step (e.g. to produce sodium hydroxide). The pilot plant has been running for 2 years in California with a production of up to 2 tons of calcium carbonate per day.

http://www.calera.com/beneficial-reuse-of-co2/process.html

Calera

CARBONCURE

CarbonCure uses CO2 as part of the concrete making process. Reaction between cement, water and CO2 creates nanoparticles of calcium carbonate dispersed through the concrete and enhances mechanical properties. Already used by over a dozen masonry producers in projects in North America. The product meets the ASTM C90 standard for load bearing concrete masonry units.

http://carboncure.com

Carbon Cure Technologies Inc

NOVACEM & CALIX

NovaCem was a spin-off from Imperial College London, since acquired by Calix, whose core process is flash calcination. NovaCem produced carbon negative concrete by mixing magnesium oxide with high purity sand to produce "carbon negative" cement. Novacem claimed that producing 1 ton of Novacem cement would absorb up to 100kg more CO2 than emitted at similar cost by conventional Portland cement.

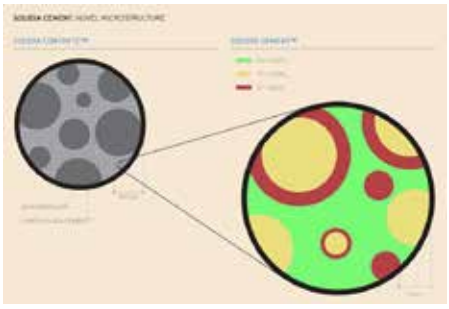
http://www.calix.com.au/endex_reactor_technology*.html

Novacem

SOLIDIA TECHNOLOGIES

Solidia Technologies injects CO2 into concrete during the manufacturing process to give a calcium silicate microstructure. Existing materials and equipment are used, the process temperature is 30% lower, 60-100% of water is recycled and less time is required (<24 hr) than traditional Portland cement manufacturing. The product sequesters 5% carbon dioxide by weight and is structurally accredited (ASTM standards).

http://solidiatech.com/wp-content/uploads/2015/04/Lafarge-Solidia-final-EN.pdf



Solidia Tech

NOISE REDUCTION

NANOSOFT (NOISE-REDUCING SURFACING)

Nanosoft ensures a 9 dB(A) decrease of traffic noise compared to conventional mixes, dividing noise power by a factor of 8.

http://www.irfnet.ch/files-upload/pdf-files/IRF_BP_Environment_Web.pdf

Colas

NOISE BARRIER (TUNNEL)

Barriers can prevent noise from the highway disturbing residents and local wildlife. These include both reflective technologies, like concrete barriers that reflect the sound back towards the road and absorption technologies that dissipate the sound into a material.

https://www.soundfighter.com/products-appliances/roads-and-highways

Highway Noise Barrier

RENEWABLE ENERGY AND ENERGY HARVESTING

BIOENERGY ON HIGHWAYS

Biomass production could enhance the visual quality and air quality along the highway and generate energy. A set of criteria by which the feasibility of a biocrop program could be evaluated: crop type, erosion, structural integrity of the road and near the road, habitat issues, line of sight issues, risk management issues, ecological impacts, and water quality issues.

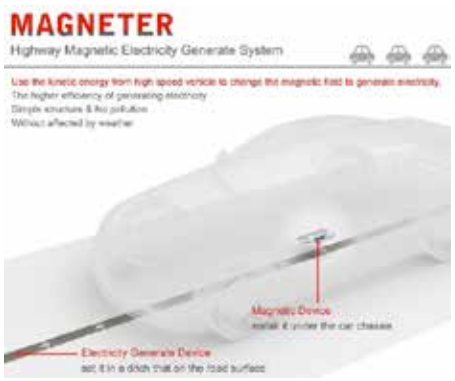
http://www.fhwa.dot.gov/real_estate/publications/alternative_uses_of_highway_right-of-way/rep03.cfm#foot30

NCDOT

ENERGY HARVESTING FROM BRAKING ON HIGHWAYS

The American company New Energy Technologies Inc. and the UK's Highway Energy Systems Ltd. are exploring opportunities to capture the energy lost in the process of a vehicle braking to generate electricity. The lost energy is captured via specially designed mats, which are installed on the road in places where vehicles slow down.

http://www.fhwa.dot.gov/real_estate/publications/alternative_uses_of_highway_right-of-way/rep03.cfm#foot30



Magnetar

LUMINESCENT SOLAR CONCENTRATORS

There is a new kind of solar PV technology called luminescent solar concentrators (LSC). The panels are translucent, colorful and also cheaper than standard PV panels. Light is absorbed by a fluorescent dye, then re-emitted but trapped in the glass, and finally collected by PV at the edge. They are alternative, but less efficient than traditional models.

http://www.wired.com/2015/08/clear-solar-panels-double-highway-sound-barriers/

Eindhoven University of Technology

PIEZOELECTRIC ENERGY ROADS

Piezoelectric crystals generate energy from the vibrations that vehicles generate as they drive along the road.

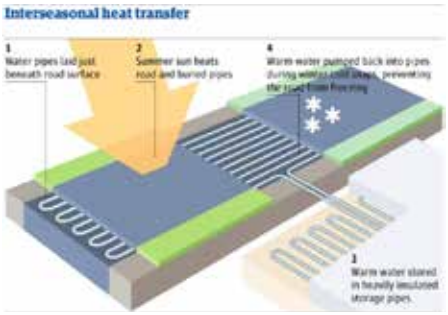
http://inhabitat.com/the-road-of-thae-future-infographic-shows-better-ways-to-build-streets/

Carloan4u.co.uk

SOLAR HEAT COLLECTORS ON THE ROAD

The UK has conducted successful trials of inter-seasonal heat transfer systems that incorporate solar energy collectors in the road and shallow insulated heat stores in the ground. Similarly, Worcester Polytechnic Institute researchers have found evidence suggesting that asphalt pavement solar collectors hold promise for energy recovery.

http://www.wpi.edu/news/20089/asphaltnews.html



null/Graphic

SOLAR THERMAL ROAD

These pipe water into the hot tarmac to harvest thermal energy, and have been demonstrated on the M1 in the UK. The heat stored in the summer was used to melt ice in the winter.

http://www.icax.co.uk/asphalt_solar_collector.html

ICAX

SOLAR TREES

Hannah Solar has installed a "solar energy tree" in Georgia. This is a structure of supported solar panels designed to resemble a tree that can power an EV charging station.

http://gold.weather.com/tv/tvshows/amhq/video/growing-solar-trees-49146

Hannah Solar

SAFETY

AVERAGE SPEED CAMERAS

Average speed cameras monitor the speed of a car between two points using automatic number plate recognition. They are used in the UK to enforce speed limits on motorways.

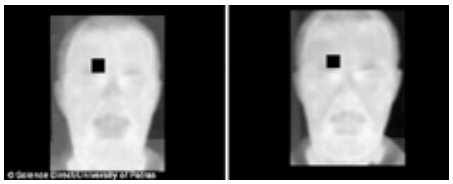
http://www.speedcamerasuk.com/specs.htm

Speed Cameras UK

CAMERAS TO DETECT DRIVER BEHAVIOUR

Cameras automatically detect bad driving (like drunk driving) and alert other road users. Proposed systems use lasers to spot alcohol vapour in the air in moving cars or use thermal cameras to see changes in the face caused by alcohol flush.

http://www.strathclydecameras.com/News/Latest-News/CAMERAS-CHANGING-DRIVER-BEHAVIOUR/



Daily Mail

CCTV FOR VEHICLE IDENTIFICATION

CCTV can be used to identify vehicles via license plate recognition. These cameras are widely used on UK roads to track speeding or other infringements of the highway code, as well as for traffic surveys.

http://www.cctvcamerapros.com/License-Plate-Recognition-Camera-p/lpr-800.htm

CCTV camera pros

CRASHED CARS ON POST TO WARN OF SPEEDING

Iceland has the displays by the side of the road to graphically illustrate the dangers of speeding.

https://www.youtube.com/watch?v=QoF_vL8M-kY

Jesjer13

GUARD RAILS (CRASH BARRIERS)

Guardrails or crash barriers can help reduce highway fatalities. They can be made of rolled steel or wood and are carefully designed to increase driver safety. They are generally placed at the roadside or in the median.

http://www.southernguardrail.com/highwaysafety/tabid/64/default.aspx

MZC report

RADAR SPEED SIGNS

Radar speed signs measure the speed of passing cars and display it to the drivers. They consists of a radar to detect speed and an LED sign to display it. Some are solar powered.

https://en.wikipedia.org/wiki/Radar_speed_sign

Dwenerti

SAFETY DRONES

Drones might be immediately dispatched to an accident to assess the damage, and give emergency responders a bird's eye view. Drones have been used in Denmark and Indonesia to monitor traffic.

http://www.arrivealive.org.uk/how-can-drones-improve-road-safety/

Cycling Embassy

SENSING AND SMART HIGHWAYS

CISCO CONNECTED ROADWAYS

Network infrastructure connects intelligent transportation systems, improving traffic flow, reducing roadside incidents and providing a centralised view of highway systems. Proof-of-concept work has been done in Hamburg with smartROAD, which includes traffic management, structural sensors, environmental sensors and smart lighting.

http://www.cisco.com/web/strategy/transportation/roadways.html

FLEXI-LANE

A flexible lane using intelligent road studs and dynamic signs will switch between loading bays, parking and a bus lane throughout the day. This allows road space to be used more efficiently and the road studs will monitor traffic flow to help improve road reliability.

https://tfl.gov.uk/travel-information/improvements-and-projects/future-streets-incubator

FOREVER OPEN ROAD-AUTOMATED

The Automated Road will integrate road side intelligence with ICT applications in the vehicle, the services and the operator. Such a road will enable the deployment of tailored guidance and management systems such as speed control, road condition monitoring, tolling, and vehicle performance monitoring.

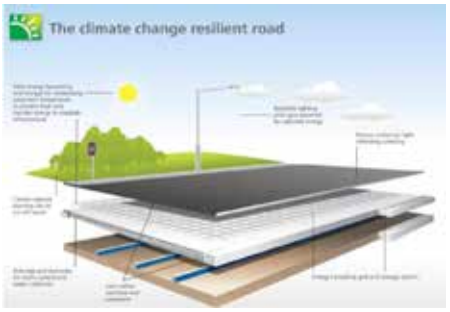
http://perso.lcpc.fr/hautiere.nicolas/pdf/2011/hautiere-piarc11.pdf

TRL

FOREVER OPEN ROAD-RESILIENT

The Resilient Road should be resilient to extremities of weather, such as temperature and rainfall, and also mitigate the negative aspects of road construction and operation, such as air and noise pollution. It should also integrate the road with its environment to make use of water, energy and planting.

http://perso.lcpc.fr/hautiere.nicolas/pdf/2011/hautiere-piarc11.pdf



TRL

INFRASTRUCTURE MONITORING SKIN

This is a 'sensing skin' made of rubber grating. When a crack develops, the skin is stretched and the colour changes.

http://www.nytimes.com/2011/03/13/business/13novel.html?_r=0

MIT

INTELLIGENT ELECTRONIC ROAD USER CHARGING SYSTEMS

An integrated road user charging system based on GPS/GNSS, GSM/GPRS and DSRC. The technology charges different fees according to the vehicles' emission class and contributes to decreased congestion.

http://www.irfnet.ch/files-upload/pdf-files/IRF_BP_Environment_Web.pdf

Kapsch

IR ROAD SENSORS

IR sensors are installed on traffic signal poles and analyse the road surface. Provides real-time info, and is less invasive/more reliable than embedded sensors. Installed in North Vancouver to measure temperature for more efficient ice/snow removal, and cost $28k.
-What measurements would be more useful on I-85? Possibly surface topology for maintenance?

http://www.arrivealive.org.uk/how-can-drones-improve-road-safety/

NS News

PIEZO-POWERED INFRASTRUCTURE SENSORS

These sensors are embedded in infrastructure and powered by vibrations and strain from the environment. The sensors use less than 800 nW of power, and data is collected wirelessly using handheld readers that scan the structure.
These are made by a start-up called Piezonix.

http://www.homelandsecuritynewswire.com/dr20140612-smart-infrastructure-sensors-are-powered-by-the-pavement-bridges-they-monitor

Piezonix

SMART OWL: SOUND

Polysolar Ltd has been working with the University of Warwick and Sentec Ltd to create a commercially-viable, easily integrated family of autonomous pollution sensors – Solar Owls. The first to be developed is the Solar Owl noise pollution sensor.

http://www.sentec.co.uk/newsandthinking/news/solar-owl

Sentec

V2V (VEHICLE-TO-VEHICLE) COMMUNICATION

CarSpeak is a communication system enabling a car to query and access sensory information captured by other cars in a manner similar to how it accesses information from its local sensors (V2V (vehicle-to-vehicle) communication).

http://ares.lids.mit.edu/fm/projects.html

DOT

TRAFFIC MONITORING AND MANAGEMENT

3M DIAMONDGRADE REFLECTIVE SHEETING

Traffic signs made of this reflective sheeting have longer effective life cycle and improved visibility. It has been adopted by an Illinois Department of Transport road agency to replace overhead signs on the state's roadways.

http://www.irfnet.ch/files-upload/pdf-files/IRF_BP_Environment_Web.pdf

3M

E-PAPER ROAD SIGNS

These run on sunlight and consume up to 99% less energy than their LCD counterparts. The display can maintain an image with no power. The signs are connected to the Internet of Things, and display changing road information.

http://www.springwise.com/sydneys-e-paper-road-signs-smart-energy-efficient/

Springwise

ELECTRONIC ROAD PRICING

This is an electronic toll collection scheme designed to manage traffic flow in congested areas. The charge for passing through a gantry depends on the location and time on the highway.

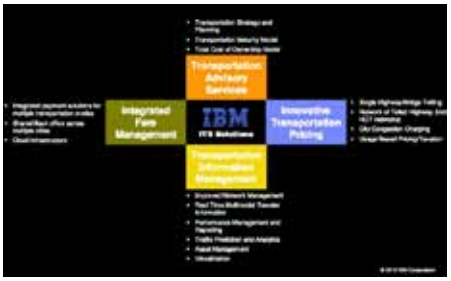
http://content.time.com/time/photogallery/0,29307,2056669_2249180,00.html

SAM KANG LI FOR TIME

IBM'S INTELLIGENT TRANSPORTATION SOLUTION

This gives operators a way to monitor traffic events and conditions through data collection from a variety of roadside devices. The system allows advanced analytics and predictive capabilities in the future for traffic prediction, incident detection, and other roadway optimisation capabilities.

http://www.roadtraffic-technology.com/news/newsibms-intelligent-transportation-solution-to-improve-traffic-flow-for-njta-4583535/



IBM

INRIX TRAFFIC MONITORING

Denmark uses GPS probe data to monitor traffic on a 4000 km road network. The system doesn't use sensors, but tracks connected cars and smart devices that use INRIX's technology.

http://www.ctvnews.ca/lifestyle/smart-roads-denmark-adopts-gps-monitoring-system-1.2453707

INRIX

OPTASENSE

Optasense is a traffic-monitoring system that uses fibre optic cables already installed along the road. It sends a laser down the cables to measure disturbances every 10m using microphones.

http://www.optasense.com/2015/02/optasense-partners-with-siemens-to-exploit-das-technology-for-traffic-monitoring-in-the-uk/

Traffex

QUICKCHANGE MOVEABLE BARRIERS

The QMB system prevents congestion at motorway exits, allowing for rapid movement of the safety barrier delimiting motorway deviations and lanes. QMB involves a machine that shifts the barrier one lane sideways at a rate of 9 and 15 km/h.

http://www.irfnet.ch/files-upload/pdf-files/IRF_BP_Environment_Web.pdf

Snoline

SMART MOTORWAY

Smart motorways use active traffic management (ATM) techniques to increase capacity by use of variable speed limits and hard shoulder running at busy times. Overhead signs tell drivers when the hard shoulder may be used and updates the speed limit. This keeps the traffic moving at a consistent speed and reduces overall congestion.

http://www.highways.gov.uk/roads/road-projects/m6-birmingham-box-phase-3/

UK DOT

SURTRAC (SCALABLE URBAN TRAFFIC CONTROL)

SURTRAC is an adaptive traffic control system developed by CMU, which uses the city cameras already in place and optimises the control of traffic signals at intersections in response to real-time traffic conditions so as to improve traffic flow. SURTRAC at each intersection relays traffic information to the next intersection. This communication enables each one to respond with light changes.

http://www.post-gazette.com/local/city/2013/11/25/CMU-helps-East-Liberty-run-smoother-pedestrians-next-CMU-s-E-End-traffic-effort-turns-to-pedestrian-safety/stories/201311250114

PG graphic: Smart traffic signals
(Click image for larger version)

CMU robotics Institute

VARIABLE SPEED LIMITS

Variable speed limits can be used to respond to changing weather, and to improve traffic flow.

http://www.sabre-roads.org.uk/wiki/index.php?title=Variable_Speed_Limit

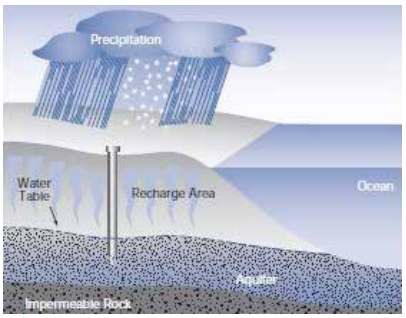
BBC

WATER MANAGEMENT

GROUNDWATER RECHARGE AND RETENTION

This describes ways to collect water from roads – like culverts, drains, borrow pits, road surface, and river crossings. It reduces water damage to roads.

http://upgro.org/category/project-news/optimising-road-development-for-groundwater-recharge-and-retention/



EPA

PERMEABLE CONCRETE

Topmix Permeable concrete allows water to seep through it rather than sitting on top to combat flooding. A video of the material being tested in a car park shows the concrete "drinking" 880 gallons of water in around a minute.

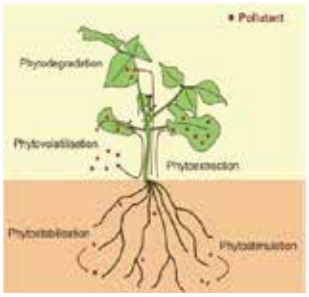
https://www.youtube.com/watch?v=ed-jiOXO3aQ&feature=youtu.be

Tarmac

PLANTING HYPERACCUMULATORS

Hyperaccumulators are plants that are effective at absorbing organic molecules and heavy metals. They may be planted to clean up run-off. Phytoremediation through chelating agents is another possible approach. Unlocking value via 'phytomining' is a possible extension of this technology, but is further out and less plausible at this stage.

http://www.sciencedirect.com/science/article/pii/S0168945210002402

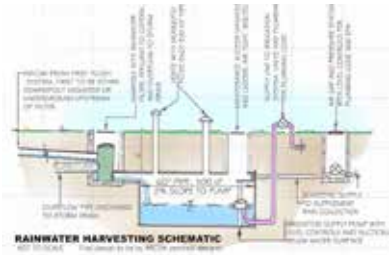


Pilon-Smits (2005) Annual Review of Plant Biology

RAINWATER FILTERING

Filters incorporated in the road can purify harvested rain water in large pits under the road. This has been done in India using pits and trenches filled with gravel.

http://www.rainwaterharvesting.org/Urban/Components.htm



Calibre Engineering

WILDLIFE AND VEGETATION

BIO-RETENTION AREAS

Sixteen bio-retention areas (engineered rain gardens) were created in the medians of the Coastal Highway to slow down and filter storm water off the road. Each area is estimated to trap and filter 0.15 pounds of phosphorus and 1.5 pounds of nitrogen every year.

http://www.inlandbays.org/anchorage-canal-retofit-project/

Inland Bays

CAMERA TRAPS AND DISPLAYS

Camera traps and displays show drivers the local wildlife.

http://www.wideopenspaces.com/camera-traps-capture-serengeti-wildlife-selfies-pics/

D'camera group

MIMAR

MIMAR is a map, providing road users with information on road sections with a high risk of disturbing animals in their natural surroundings and thus a high risk of accidents involving animals as well as areas with a high environmental value, due to bio-diversity.

http://www.irfnet.ch/files-upload/pdf-files/IRF_BP_Environment_Web.pdf

Asociatión Española
de la Carretera

ROADSIDE VEGETATION MANAGEMENT

The edge of the pavement is maintained in a vegetation-free condition in a 2 to 10 foot band along most sections of highway. Experience had shown this to be an efficient and effective way to facilitate stormwater run-off, preserve pavement life, reduce fire potential, and provide for traffic visibility.

http://www.wsdot.wa.gov/Maintenance/Roadside/research.htm

IRVM

WILDLIFE DETECTORS

In Australia and Canada, sensors detect wildlife, and warn drivers. Sensors include laser tripwires and radar systems.

Bond, Amy RF, and Darryl N. Jones. "Wildlife Warning Signs: Public Assessment of Components, Placement and Designs to Optimise Driver Response." Animals 3.4 (2013): 1142-1161.

GovTech JHOC

WILDLIFE GREEN BRIDGES

Wildlife green bridges on the EU-Russian highway will provide vegetated green corridors which the animals will accept as just part of the forest. Along with five locations for these, there are to be another four animal underpasses.

http://www.worldhighways.com/sections/key-projects/features/new-eu-russian-highway-connection/

Worldhighways

WILDLIFE MONITORING DRONES

Drones keep track of wildlife in the area, to better understand the real impact of the highway. Drones have been used to monitor bird life and for nature reserve monitoring in Surinam.

https://www.audubon.org/magazine/july-august-2014/drones-take-wildlife-conservation-tool

Audobon Magazine

REPORTS, TRIALS AND PROJECTS

ALTERNATIVE USES OF HIGHWAY RIGHT-OF-WAY

Transportation agencies can get information that will better enable them to consider the implications and evaluate the feasibility of accommodating renewable energy technologies and alternative fuel facilities within highway right-of-way(ROW). It covers solar, wind, and biofuels.

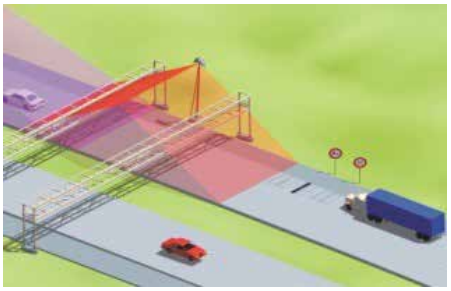
http://www.fhwa.dot.gov/real_estate/publications/alternative_uses_of_highway_right-of-way/rep00.cfm#exec

CFBF

ASSET-ROAD

The project aims to use available technologies (high-speed weigh-in-motion (WIM) system, RFID tagging special cameras and 3D equipment) to detect offences automatically to prevent road accidents, especially those linked to heavy goods transport.

http://ec.europa.eu/research/transport/projects/items/innovative_monitoring_for_road_transport_safety_en.htm



Project ASSET

ATTICA TOLLWAY

On this high way, there are six noise-measurement stations and eight air pollution-measurement stations. There are extensive sewage and flood-protection works to collect superficial water run-off.

http://www.irfnet.ch/files-upload/pdf-files/IRF_BP_Environment_Web.pdf

Attica Tollway

COPENHAGEN'S INTELLIGENT TRANSPORT SYSTEMS

Intelligent transport systems will control traffic light remotely and adapt to weather and real-time traffic conditions. The system will use smart phones to relay information with sensors. The project entered a roll out phase in 2015.

http://www.thelocal.dk/20150202/copenhagen-to-roll-out-new-smart-traffic-systems

Christopher Berggren

DANISH OUTDOOR LIGHTING LAB

This is a demonstration project to test and demonstrate about 50 different networked street lighting systems.

http://www.nytimes.com/2014/12/09/business/energy-environment/copenhagen-lighting-the-way-to-greener-more-efficient-cities.html?_r=0

DOLL

ELECTRIC VEHICLES PROJECT

This is a pilot project to collect and analyse data to characterise vehicle use in diverse topographic and climatic conditions, evaluate the effectiveness of charging infrastructure, and conduct trials of various revenue systems for commercial and public charging infrastructures.

http://www.theevproject.com

The EV project

FORD SMART MOBILITY PLAN

This project focuses on two areas of mobility: flexible use and ownership, and multimodal urban travel solutions. Flexible use and ownership models include Ford Credit, which is a P2P car sharing program, and GoDrive which is an on-demand public car-sharing pilot. MoDe:Flex is Ford's eBike, which is connected with the rider's smartphone app to provide information on weather, congestion, route planning and fitness.

https://media.ford.com/content/fordmedia-mobile/fna/us/en/news/2015/06/23/ford-smart-mobility-shifts-from-research-to-implementation.html

Ford

FORD'S LEARNING FROM MOBILITY EXPERIMENTS

Ford's infoCycle research instigated how bicycles can be best used in urban environments. Learnings include:
1) Both consumers and cities can use data from bike sensors
2) Bike sensor data can provide information about traffic patterns, pedestrians and road conditions
3) Data can be used to analyze road quality and identify traffic patterns

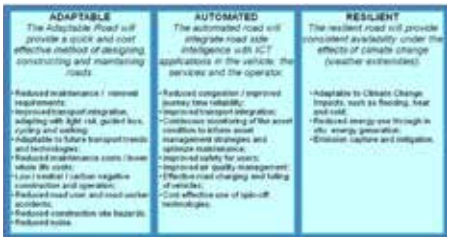
https://media.ford.com/content/fordmedia-mobile/fna/us/en/news/2015/06/23/ford-smart-mobility-shifts-from-research-to-implementation.html

Ford

FOREVER OPEN ROAD

A new road concept which aims to build an adaptable, automated and climate change-resilient road. Such a road would be constructed from prefabricated elements.

http://www.worldhighways.com/sections/eurofile/features/europes-roads-need-innovation-and-research/



FEHRL

HIGHWAY SUSTAINABILITY CHECKLIST

The checklist was developed as an objective, non-prescriptive, broad-based tool that would support the integration of environmental stewardship practices and CSS into day-to-day highway-related practices. A compendium of possible measures associated with various phases of highway projects - from planning to design, through construction, operations and maintenance.

http://www.irfnet.ch/files-upload/pdf-files/IRF_BP_Environment_Web.pdf

Parsons Brinckerhoff

I-80 INTEGRATED CORRIDOR MOBILITY PROJECT

Project elements include: Freeway Management System (corridor-wide adaptive ramp metering including ramp metering HOV bypass lanes for transit access, and Variable Speed Limit signs), Arterial Management System, Transit Management System, Traveller Information System, Traffic Surveillance and Control System, Incident Management System, Commercial Vehicle Operations, and Integration with the SMART Corridor Program.

http://www.ccta.net/_resources/detail/37/2

I80 project

IMPACT OF VEGETATION ON MOTORWAY AIR QUALITY

The Air Quality Innovation Program in The Netherlands conducted experiments to investigate the impact of vegetation on air quality near motorways. They found that immediately alongside the road the impact of vegetation on air quality is not significant. Further away (50-100 m from the road) the effects of roadside trees are positive.

http://laqm.defra.gov.uk/documents/Dutch_Air_Quality_Innovation_Programme.pdf

DEFRA

INNOVATIVE PRACTICES FOR GREENER ROADS

The International Road Federation has written a report describing a number of suggestions for sustainable roads. These include Mimar, sustainable building materials and smart road systems.

http://www.irfnet.ch/files-upload/pdf-files/IRF_BP_Environment_Web.pdf

IRF

INNOVATIVE ROAD PROJECT (RUSSIA)

This is a pilot project which aims to stimulate mass usage of innovative materials and technologies in road construction, and develop the market for innovative production in road-construction industry. Technologies tested will include materials that increase wear-resistance, and cracking-resistance, improve water permeability and road bed resistance against fluidity of soils, intellectual transportation system, and energy-independent lighting system.

http://www.worldhighways.com/sections/general/news/new-innovation-in-russia-for-road-connections/

World highways

INSTITUTE FOR SUSTAINABLE INFRASTRUCTURE

The Institute for Sustainable Infrastructure is a not for profit organisation that is developing a sustainability rating system for civil infrastructure including highways. Members include Skanska and Havard University.

https://www.sustainableinfrastructure.org/

Institute for Sustainable Infrastructure

Sustainable Infrasturcture

INTELLIGENT INFRASTRUCTURE FUTURES

This Foresight report, by the UK Government Office for Science, explored the transport challenges faced by the UK up to 2050.

https://www.gov.uk/government/publications/intelligent-infrastructure-futures

Office of Science and Technology

MISSOURI'S "ROAD TO TOMORROW" INITIATIVE

This project's vision was to help people from inside and outside the state to come up with a way to rebuild the highway system. Partners and technology programs are currently being finalized.

http://www.bizjournals.com/kansascity/news/2015/06/03/missouri-smart-highway.html

Missouri Department of Transport

ROAD A404

This development included ways to reduce road crashes, including resurfacing, and improved road markings, lowering the speed limit, renewing cat's eyes, improving junctions with high friction surfacing, and reflective bollards, and improving pedestrian crossings.

http://www.roadsafetyfoundation.org/media/32555/star-rating-roads-for-in-built-safety.pdf

DOT

SAFE SYSTEM MODEL

International organisations and leading countries in road safety have endorsed the so-called 'safe system' approach to reducing serious trauma on the road transport system. The model covers the road, the vehicle, and driver behaviour as the three main factors contributing to safety.

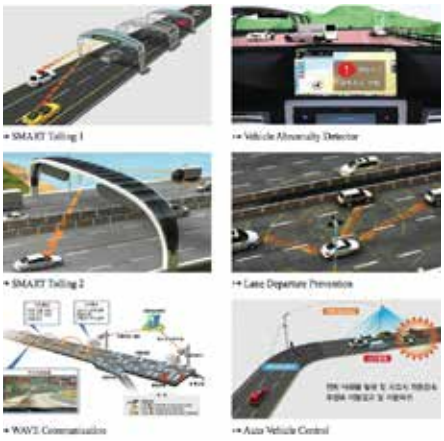
http://www.roadsafetyfoundation.org/media/32555/star-rating-roads-for-in-built-safety.pdf

Road Safety Foundation

SMART HIGHWAY PROJECT

This is an initiative by the Korean government, which aims to reduce the accident rate and help people use expressways more conveniently by converging information, automobile, and road management technologies.

http://www.businesskorea.co.kr/article/1374/smart-highway-aiming-build-world%E2%80%99s-most-intelligent-highways#sthash.BS1IJM17.dpuf



SMART highway project

"SMART" HIGHWAY

The designer proposed several features including dynamic, temperature-sensitive markings that could change to indicate weather conditions; glowing road markings; wind indication lights; and a lane embedded with induction coils to charge electric cars as they drove over.

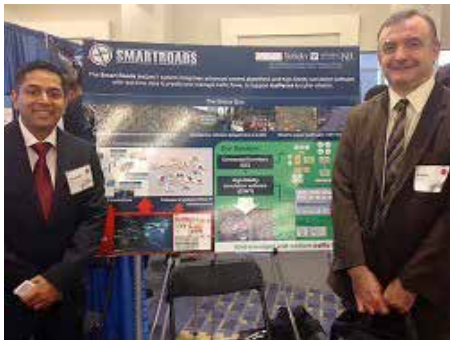
http://www.cnet.com/news/glow-in-the-dark-smart-highway-opens-in-the-netherlands/

Studio Roosegaarde

SMARTAMERICA SMART ROADS

This is a set of projects including the University of California, Berkley and Vanderbilt University working on smart transportation systems. This includes sensors, computing and networking.

http://www.nist.gov/el/smartamericaexpopresentations.cfm



Vanderbilt University

SOLAR ENERGY AND HIGHWAY ROW

This uses photovoltaic (PV) technology mounted on a noise barrier. The energy generated is used to power facilities such as LED display structure, water treatment systems nearby, or is sold to utility companies.

http://www.fhwa.dot.gov/real_estate/publications/alternative_uses_of_highway_right-of-way/rep03.cfm#sec3.1

Oregon DOT

STAR RATINGS FOR ROAD SAFETY

iRAP and the Road Safety Foundation have suggested a star rating for roads based on various measures of their safety for vehicle occupants, cyclists and pedestrians. It has currently been implemented for some roads in India.

http://www.irap.net/en/about-irap-2/star-ratings

irap

THE M6 TOLL ROAD BY ARUP

3 million tonnes of sand and gravel excavated from the site was re-used as special fills and aggregates for concrete and drainage, saving 400,000 freight journeys to and from the site. Other measures taken to mitigate the effects of the route on the local environment: the translocation of heath land; the relocation of rare plants and wildlife, and planting over 1 million new trees and shrubs.

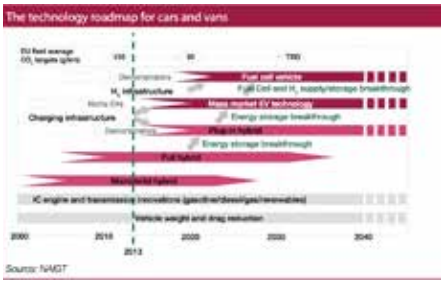
http://www.irfnet.ch/files-upload/pdf-files/IRF_BP_Environment_Web.pdf

Arup

THE TECHNOLOGY ROADMAP FOR CARS AND VANS

This shows how low carbon technologies are likely to evolve for cars over the next 30 years from internal-combustion engines, to full hybrids, plug-in hybrids, electric vehicles, and fuel cell vehicles.

http://assets.highways.gov.uk/specialist-information/knowledge-compendium/2011-13-knowledge-programme/Preparing%20the%20Strategic%20Road%20Network%20for%20electric%20vehicles.pdf

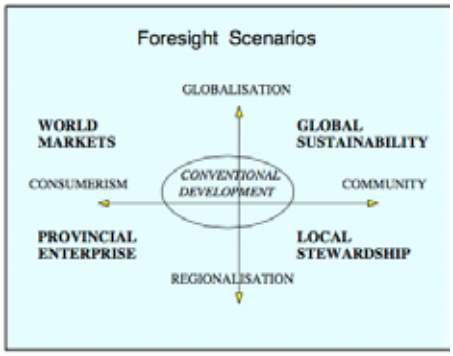


Highways Agency

THE VISION 2030 PROJECT: THE ROAD OF FUTURE

This is a report by the Highways Agency, UK. It includes twelve future propositions about transport: 1) the green highway, 2) zero accidents, 3) the connected customer, 4) freight foremost, 5) favouring public transport, 6) understanding the customer, 7) easy interchange, 8) institutional change, 9) managing supply, 10) managing demand, 11) co-operative driving on the automated highway, and 12) land use planning

http://www.ankerbold.co.uk/projects/vision-2030/



Vision 2030 project

TRANSPORT DEVELOPMENT AND INNOVATION PROJECTS (AUSTRALIA)

There are various such projects, including Intelligent Transport Systems, including automatic number plate recognition, variable message signs, and the application of GPS technology to vehicle location.

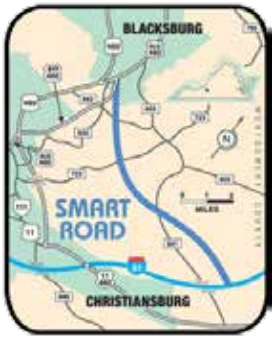
http://investment.infrastructure.gov.au/funding/innovations/

ARRB

VIRGINIA'S SMART ROAD

Virginia Highways are investing in a full-scale research facility for pavement research and evaluation of Intelligent Transportation Systems (ITS) concepts and products. The project was aiming for completion in 2002.

http://www.apps.vtti.vt.edu/PDFs/Smart%20Road.pdf



Virginia Department of Transport

VISION ZERO

The Vision Zero was started in Sweden and focuses on road safety. "Zero" means zero accidents on the road. Netherlands, UK, US , Norway have all adopted this concept.

http://www.visionzeroinitiative.com/en/Concept/

Vision Zero

WHO REPORT ON ROAD SAFETY

In 2013, the World Health Organisation wrote a report on road safety that suggested some actions to improve global road safety including: reducing speed, reducing drinking and driving, increasing seat belt use, increasing motorcycle helmet use, and wider use of child restraints.

http://www.who.int/violence_injury_prevention/road_safety_status/2013/en/

WHO

WIND ENERGY AND HIGHWAY ROW

This gives guidance on the installation of small wind turbines.

http://www.fhwa.dot.gov/real_estate/publications/alternative_uses_of_highway_right-of-way/rep03.cfm#foot30

Sam Abuelsamid

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