2016 CESTiCC Summer Workshop
Bozeman, MT
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The University of Texas at San Antonio™

Energy Harvesting and Self-power Monitoring System for the Next Generation Smart Roadways

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Research Team

Multi-disciplinary

- Electronics and Communications (Shuza)
- Electrical Engineering (Mayur, Chanda)
- Environmental & Sustainability (Clement, Tom)
- Materials Science and Engineering (Ruyan and Amar)
- Pavement Engineering (Sang, Abu, Lubinda, Samer)
- Applied Physics (Jerry)
- Structural Engineering (Arturo)
- Mechanical Engineering (George, Pranav, Babak)

Multi-Institutional

- **SwRI** = Southwest Research Institute (Industry & Applied Research)
- **TTI** = Texas A&M Transportation Institute of the Texas A&M University (Research)
- **UTSA** = University of Texas at San Antonio (Academia & Research)

Sponsor

Texas Department of Transportation (TxDOT)

405 NORTH
Sacramento

Roadway Conditions

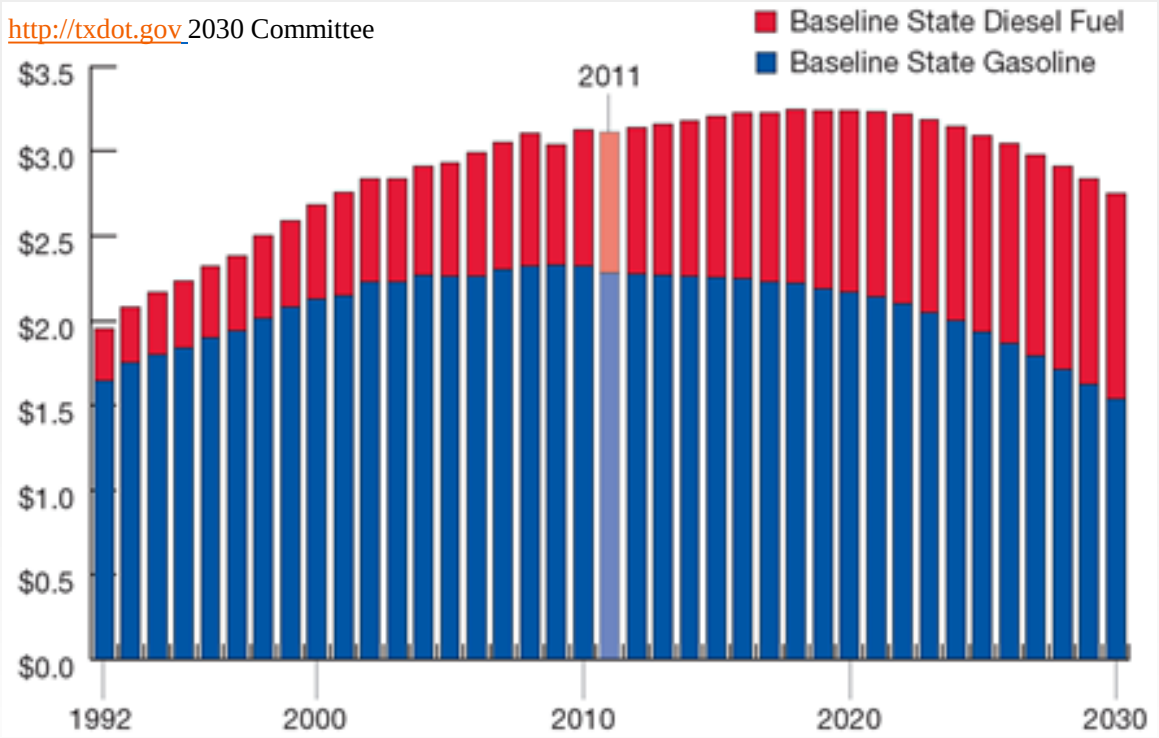
Since 1993
¢18.4 /gal

Gap will continue to grow!!

http://www.lifepushmag.com/

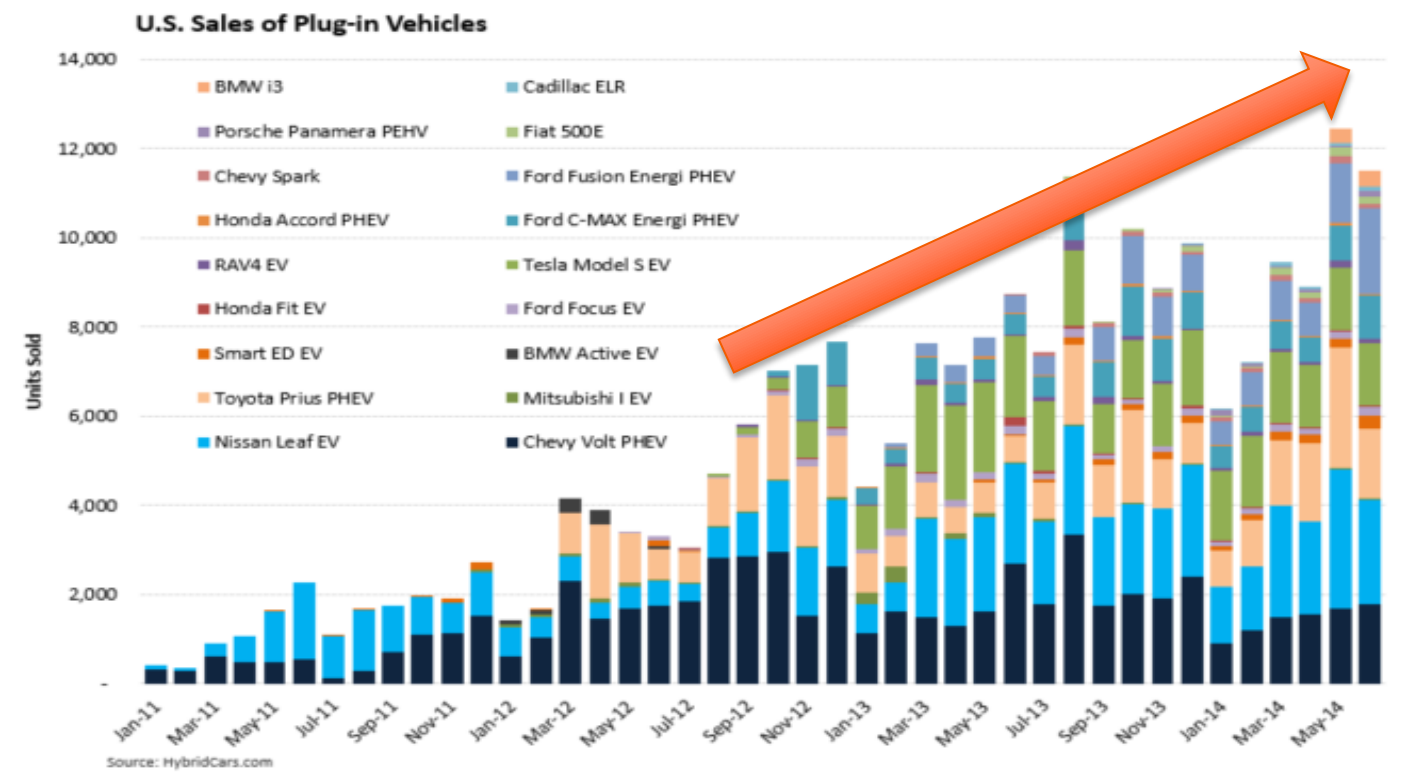
Projection of Motor Fuel Revenue ($ Billions)

http://txdot.gov 2030 Committee



U.S. Sales of EV

http://hybridcars.com

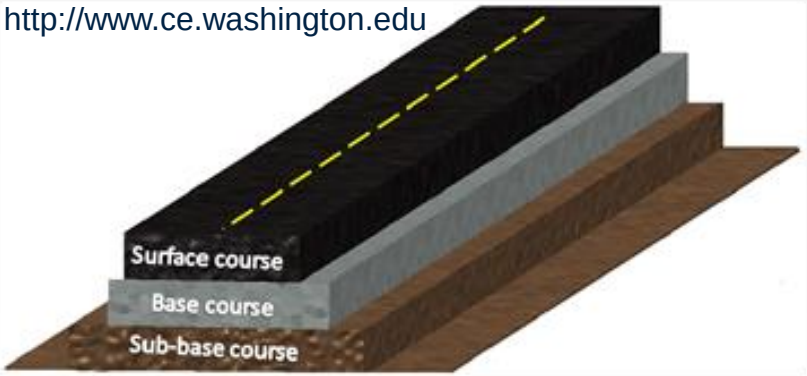


"…This year, T*esla EV Model 3 Orders Nearing 400,000….*" *www.forbes.com*
Future sales at this rate will plunge Highway Trust Fund sooner than expected

Solution

- **Develop a novel hybrid technology to harvest low-cost energy for sustainable roadways.**
- **Use this technology to monitor traffic and diagnose roadways to improve safety and minimize LCCA.**

http://www.ce.washington.edu

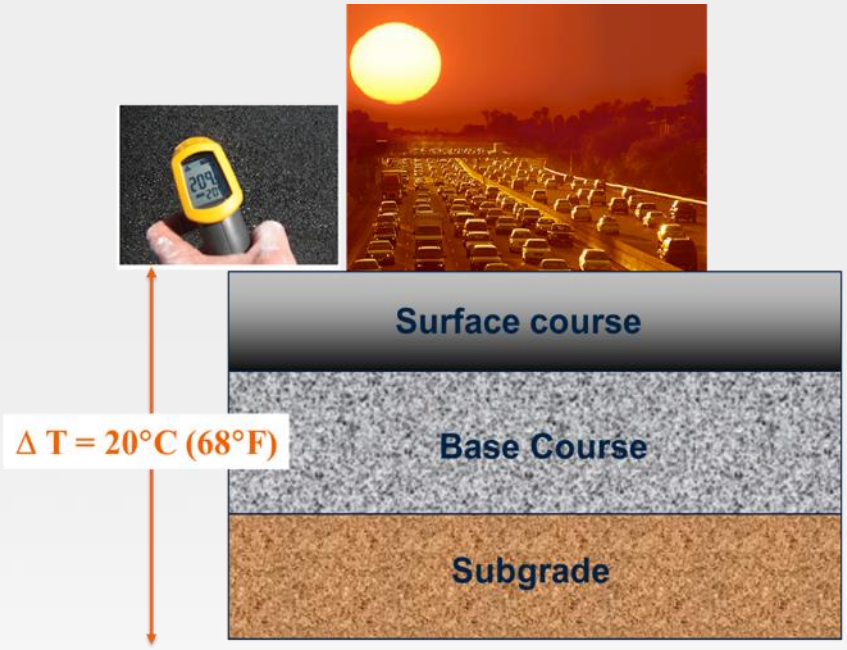


Roadway Energy Harvesting

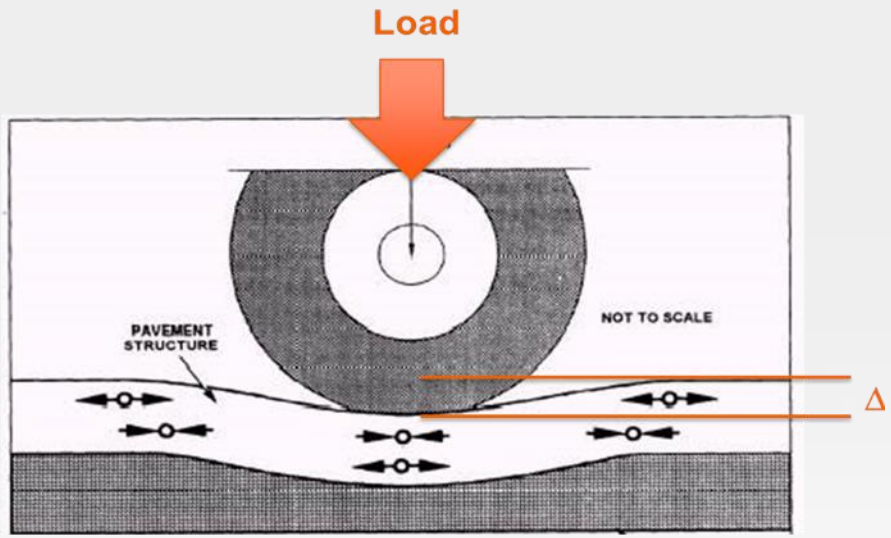
First solar bike path (Netherland)

http://www.solaroad.nl/beeldbank/

Energy Sources in Roadways



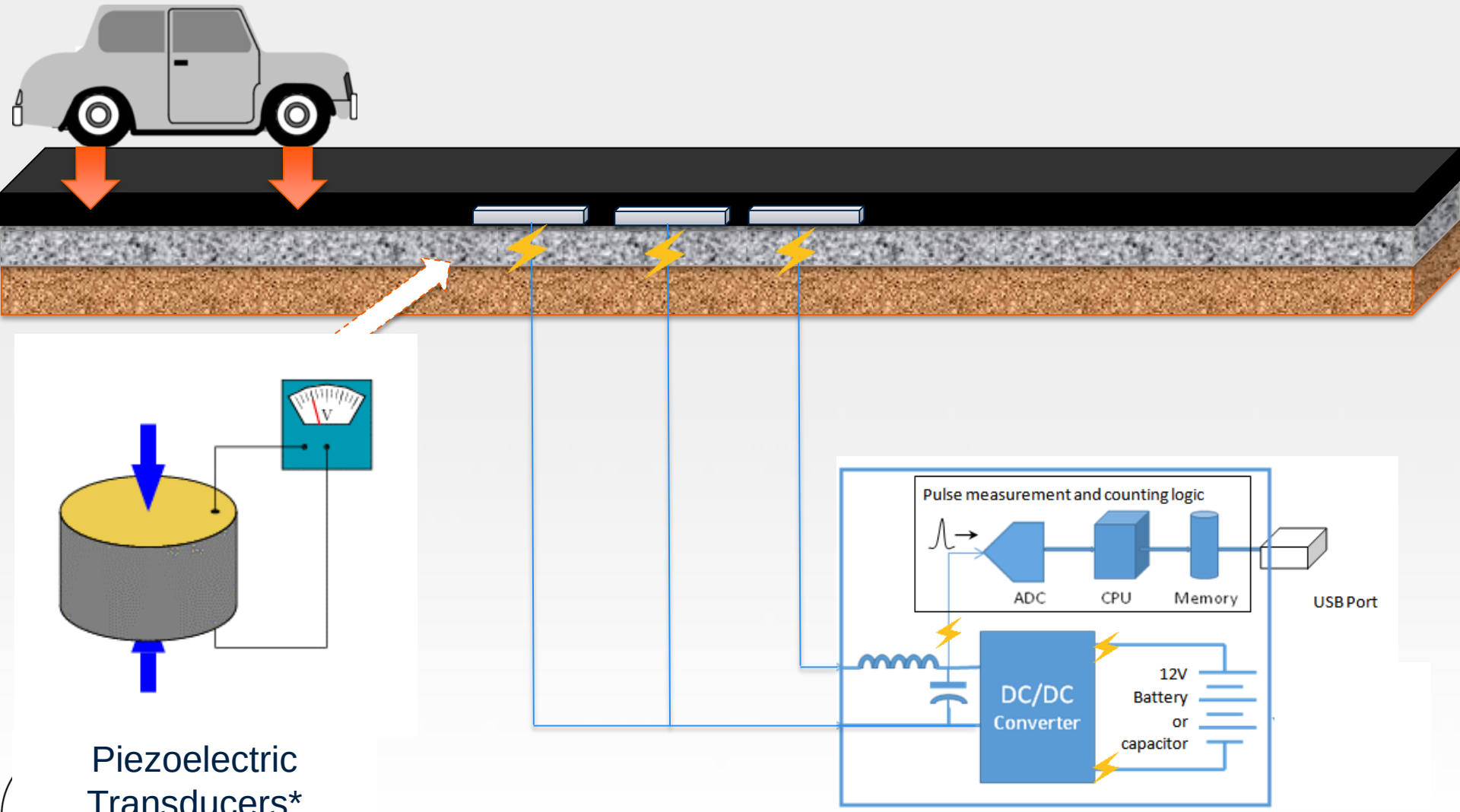
Thermal Energy = Mass x Specific Heat x ΔT



Strain Energy = Load * Δ

Wasted mechanical/thermal energy can be harnessed in the form of electric power

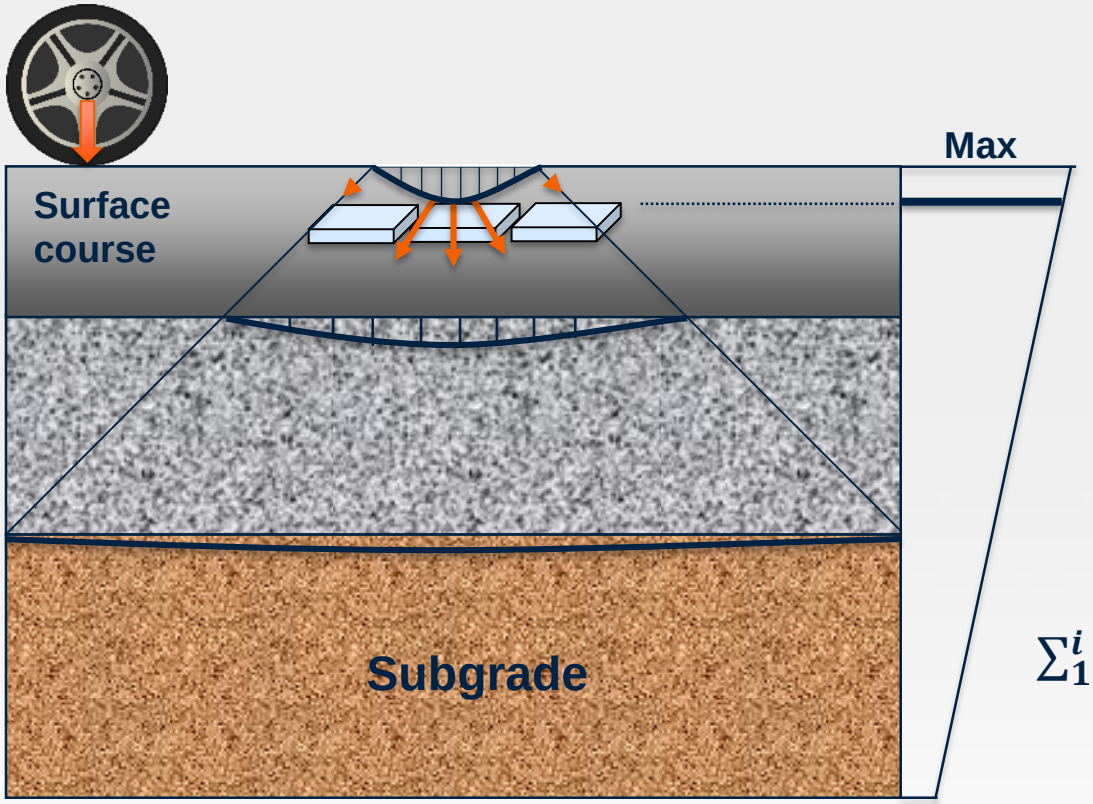
How does it work?



Piezoelectric Transducers*

*en.wikipedia.org/wiki/Piezoelectric_sensor

Strain Energy in Pavement



Strain Energy

$$\sum_1^i F_i\Delta_i = F_1\Delta_1 + F_1\Delta_1 + \ldots + F_i\Delta_i$$

$$F \times \Delta$$

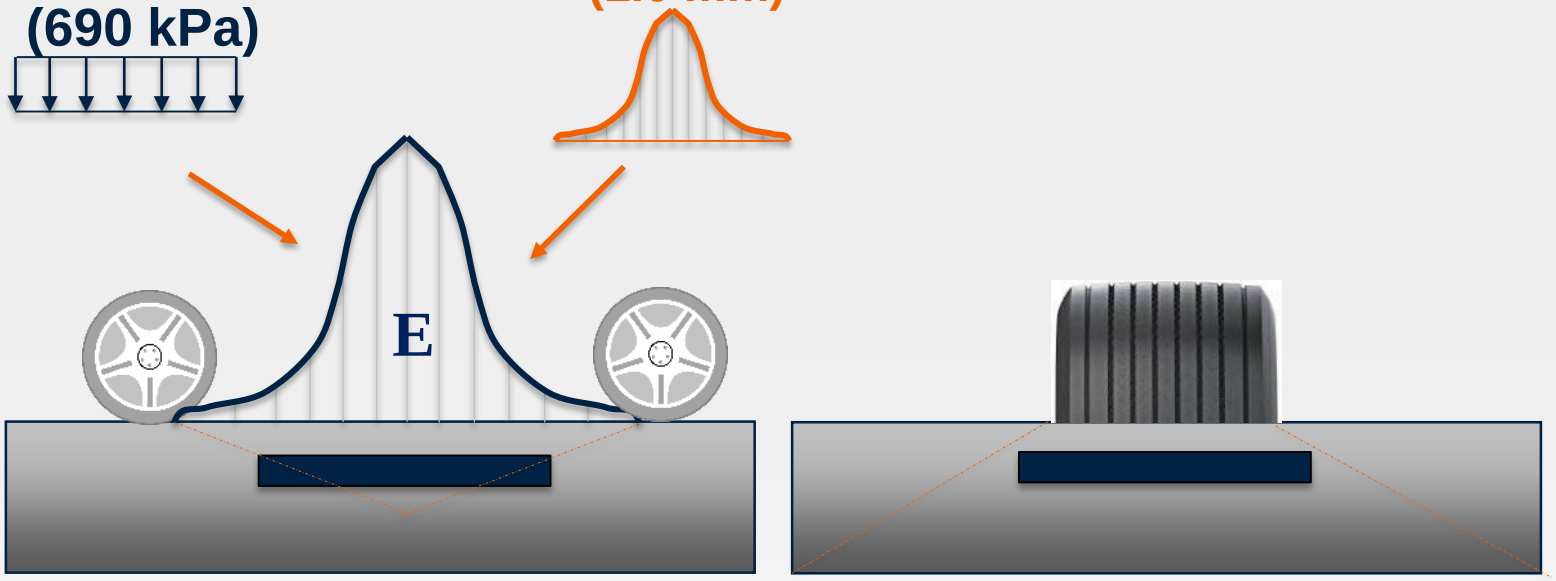
Wheel load

Avg. deformation under wheel

Strain Energy in Pavement

P= 100 psi
(690 kPa)

Δ = 0.04”
(1.0 mm)



Longitudinal view

Cross-section view

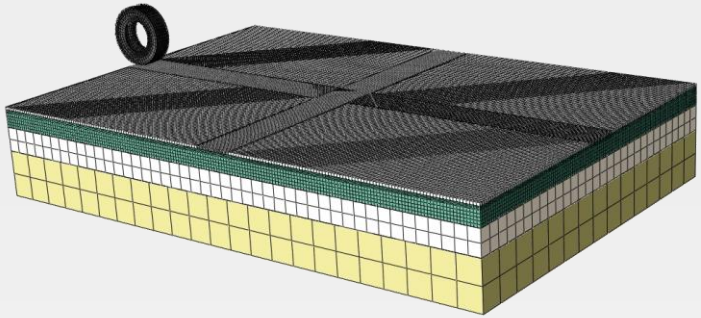
$$Energy = \int_0^L \int_0^w P\Delta(x,y) \cdot dx \cdot dy$$

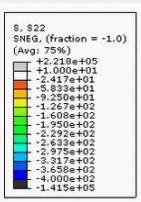
$$Energy = \frac{1}{3} x690{,}000 x \frac{1.0}{1000} x0.50 x0.50 * 2 = 116\ Joule/axle/\ ft$$

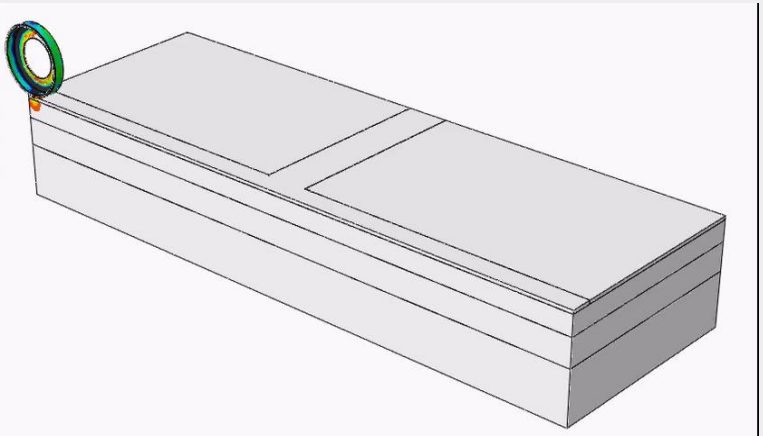
$$Energy = 116 * 5200 = 603{,}200\ Joule/axle/mile$$

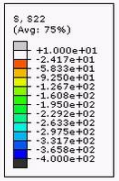
5 axles/truck
100 ADTT/lane mile
Energy/lane mile/day=0.3 GJ
Power/day= 83 kWhr

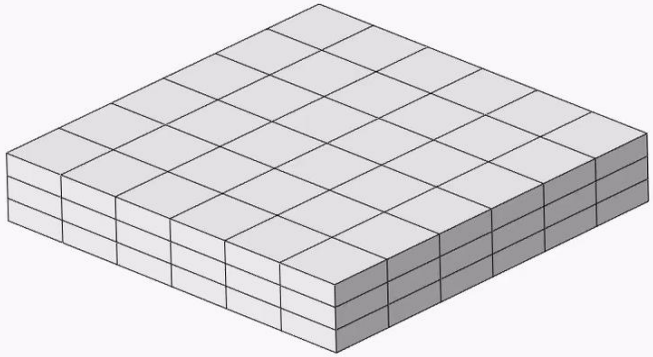
3D Finite Element Simulation of US 59



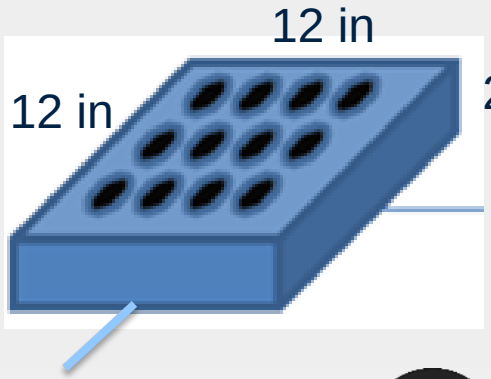


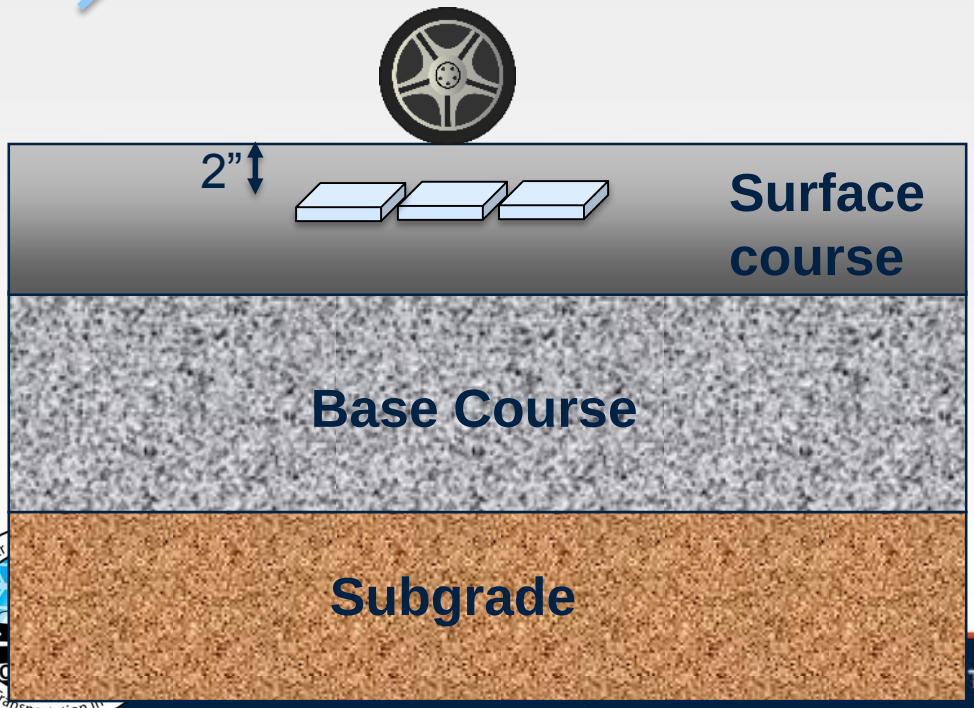


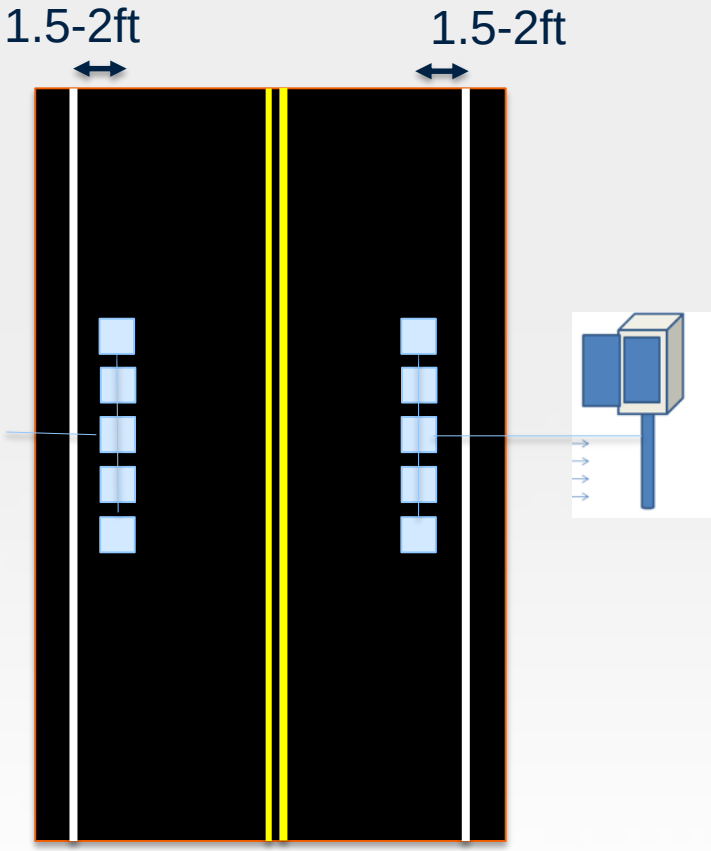




Module Geometry and Location in Pavement

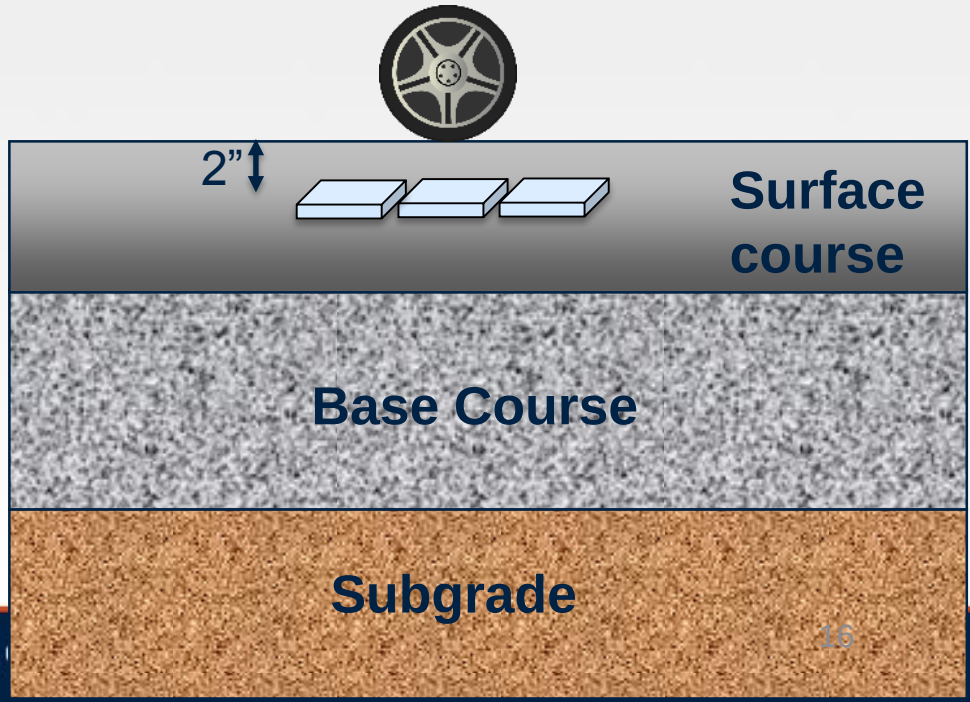


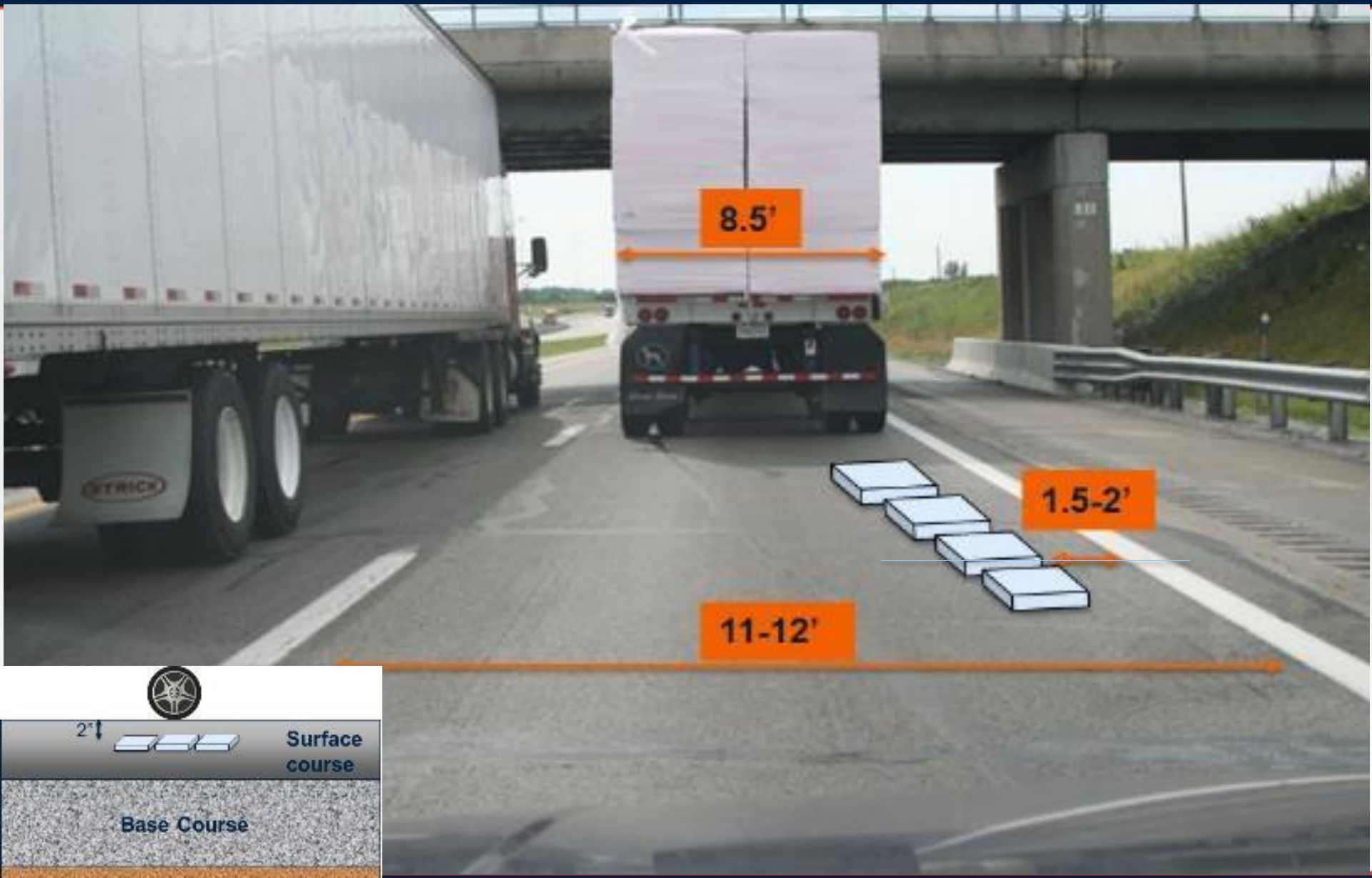




2” below Surface?

- Preserve pavement surface texture/skid
- Protection of devices from tire impact
- Taking advantage of the conventional HMA 2” lift laydown in conventional pavement placement or overlay operations

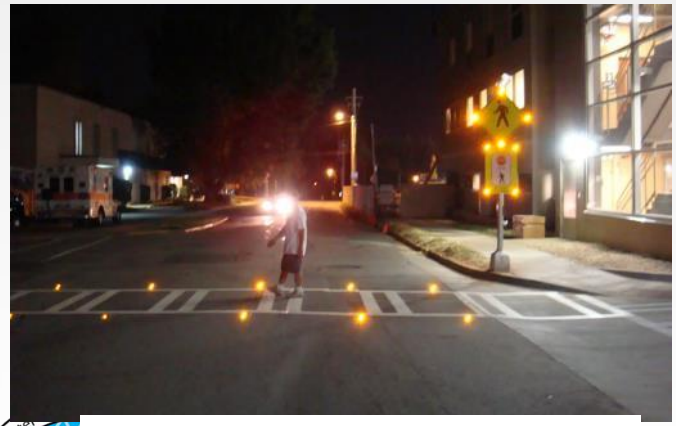



8.5'
1.5-2'
11-12'
2"
Surface course
Base Course
Subgrade

Off-grid Rural Areas

Providing source of power for:

- Traffic signals and lighting
- LED signs and marking

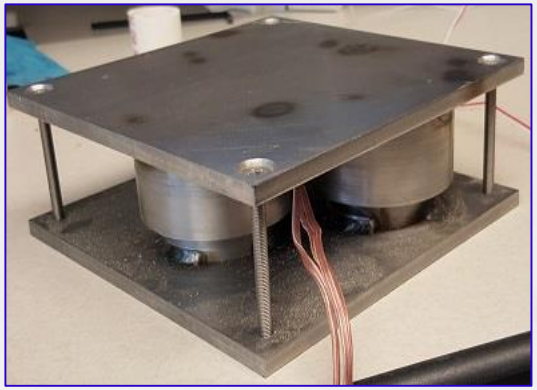


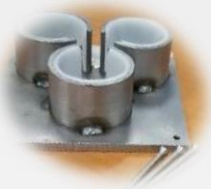
http://www.gproadwaysolutions.com/

Developed modules

Demo Package I

Demo Package II



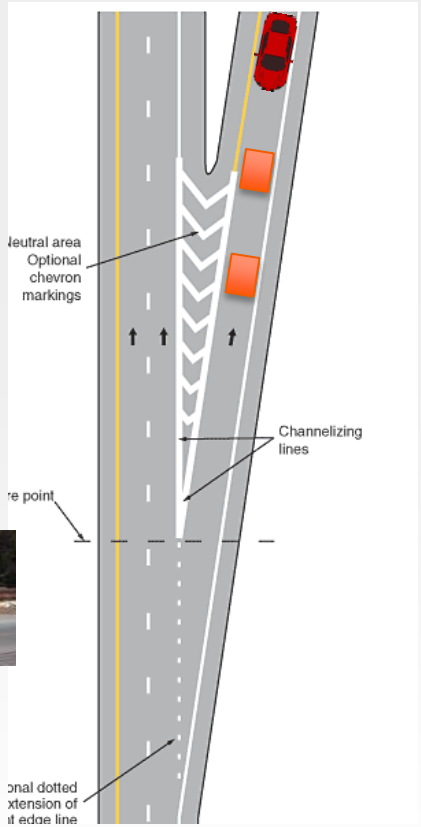


Each is instrumented with:

- **Power Conversion and Energy Storage Capabilities**
- **Multi-Mode Sensing Capabilities**
- **Data Collection and Communication Capabilities**

Traffic Monitoring

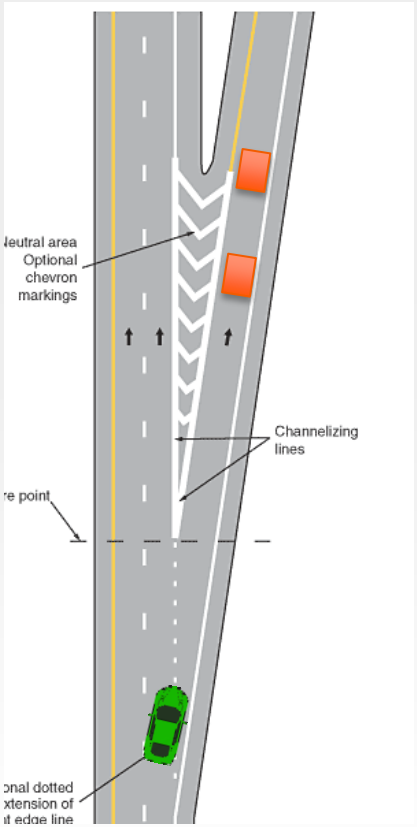
(Wrong Way Detection)



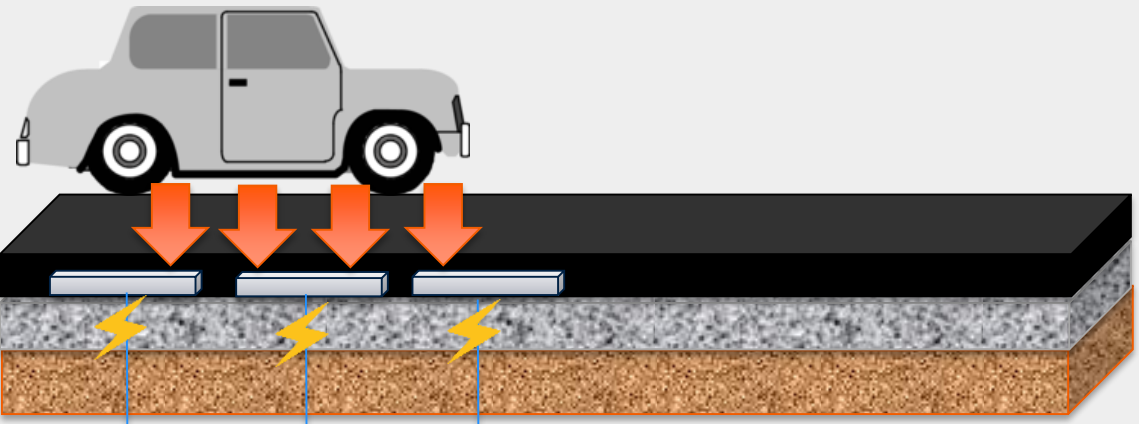
Vehicle Count
Speed
Traffic Pattern
Axle detection

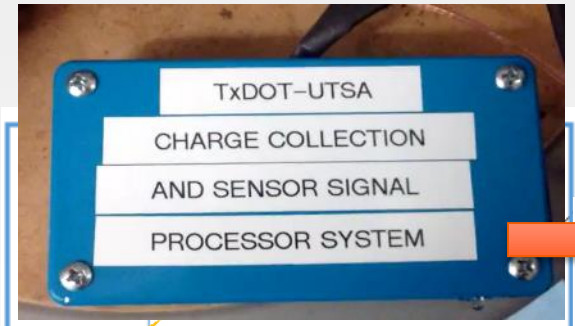
Weigh in motion*

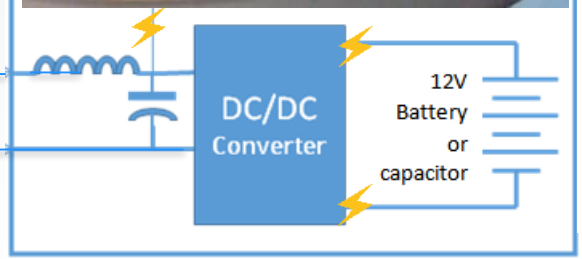
*Courtesy of International road dynamics Inc.

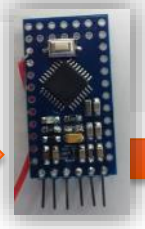


Roadway Health Monitoring (WIM replacement)









Pavement Data

Stress
Deformation
Temperature
Moisture

System Capabilities

- Self-contained continuous power generation at off-grid zones.
- Enhanced safety (high water crossing, wrong way).
- Inexpensive and unobtrusive traffic data collection
- Record pavement responses (e.g., stress/deflection)
- Vehicle to infrastructure (V2I) communication and data transfer.

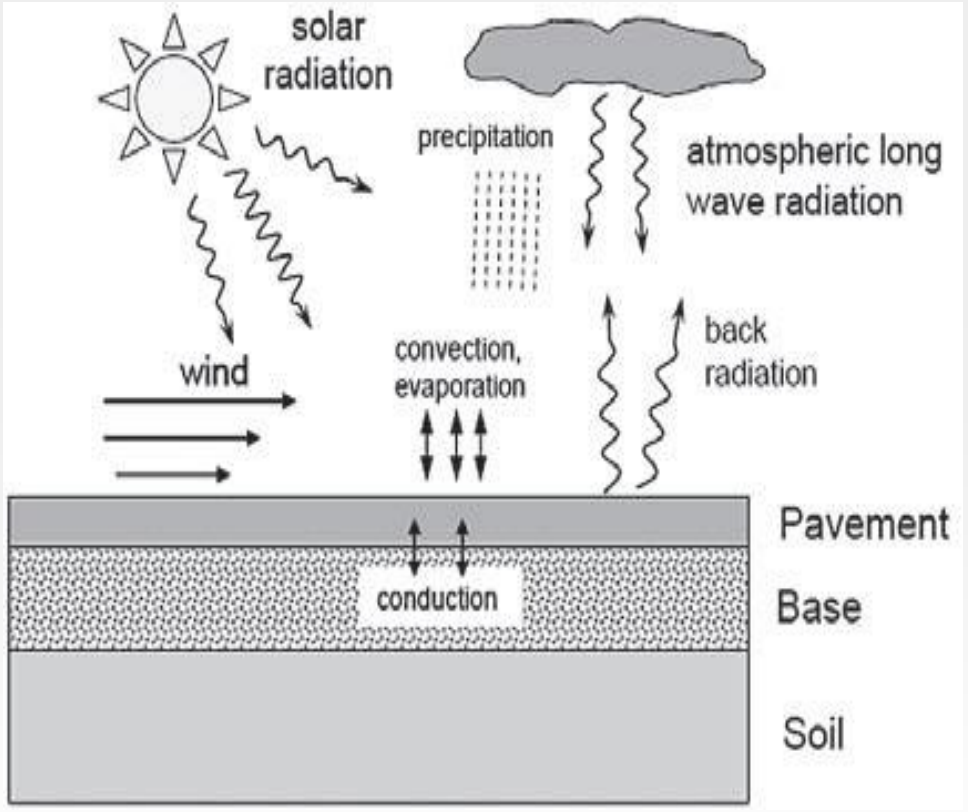
Economic Feasibility

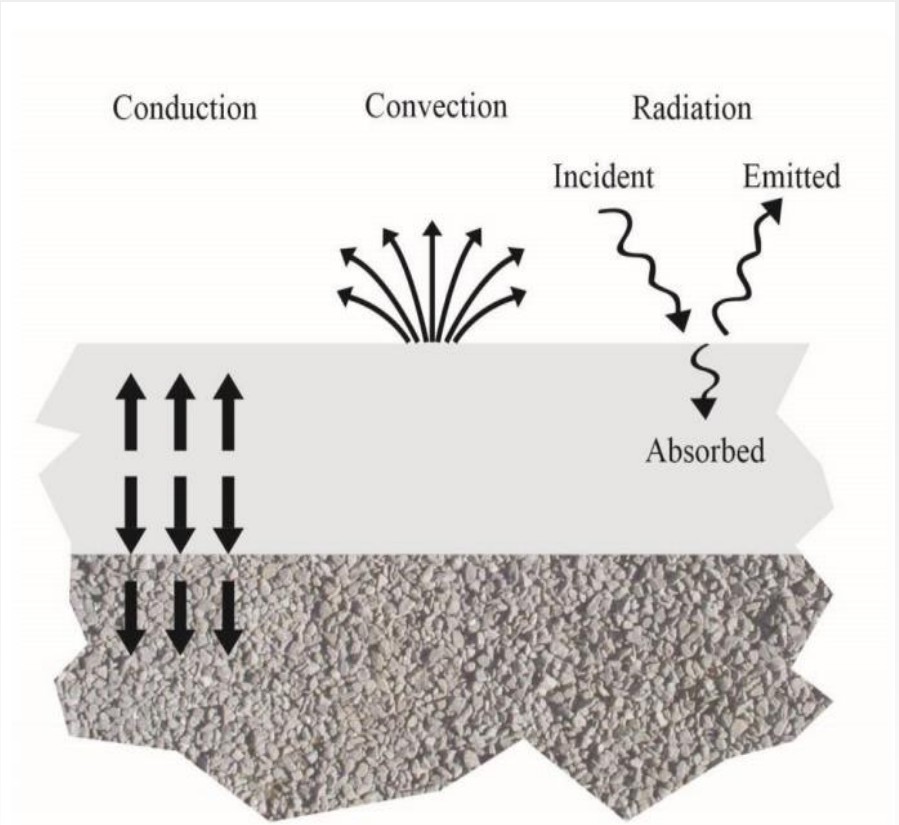
- The estimated cost is **$250** per module.
- The installation cost is marginal
- Traffic composition of 50,000 ADT, over One lane-mile of modules, will produce 110 kWh/day (household is 30 kWh/day).

- Commercial energy harvesting system cost **$2300** with much less power output and no sensing.
- Commercial WIM systems cost in the range of **$50-250k** with only sensing capability.

Thermal Energy Harvesting

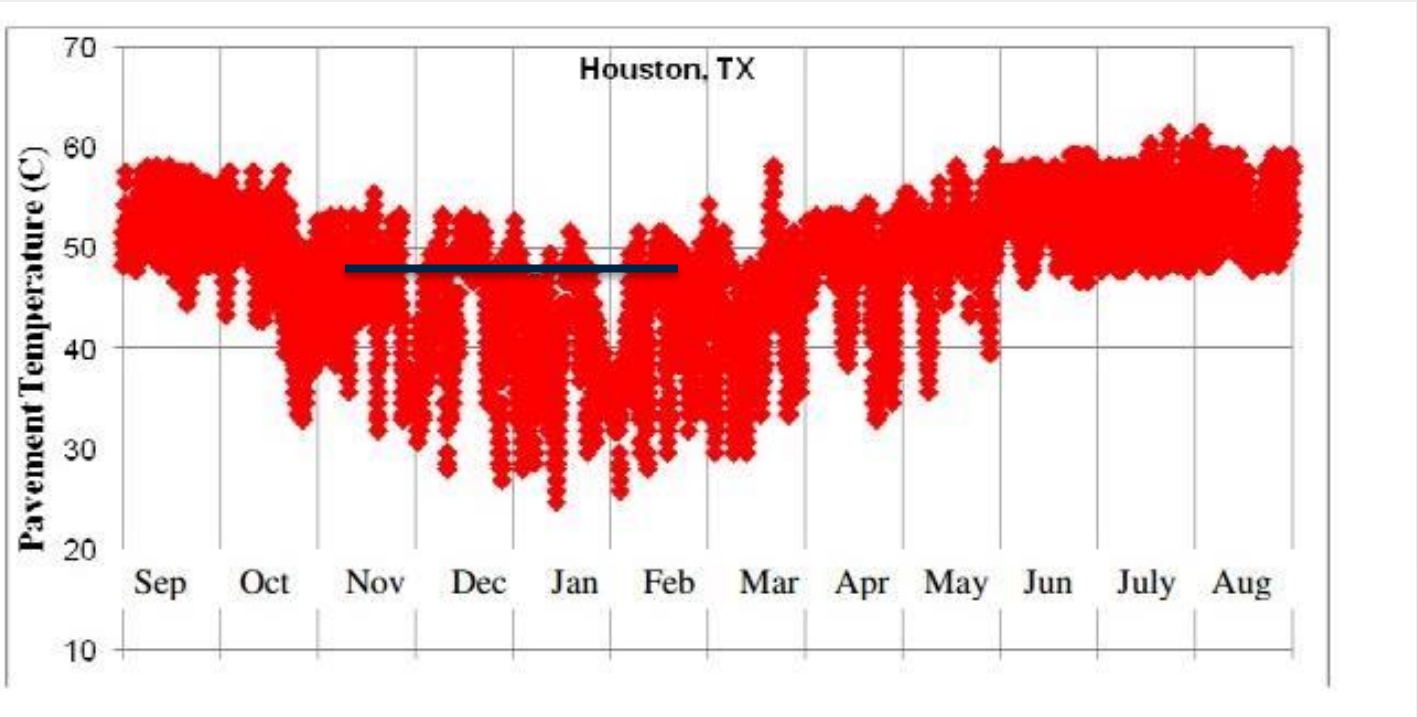
Thermal energy on asphalt pavements





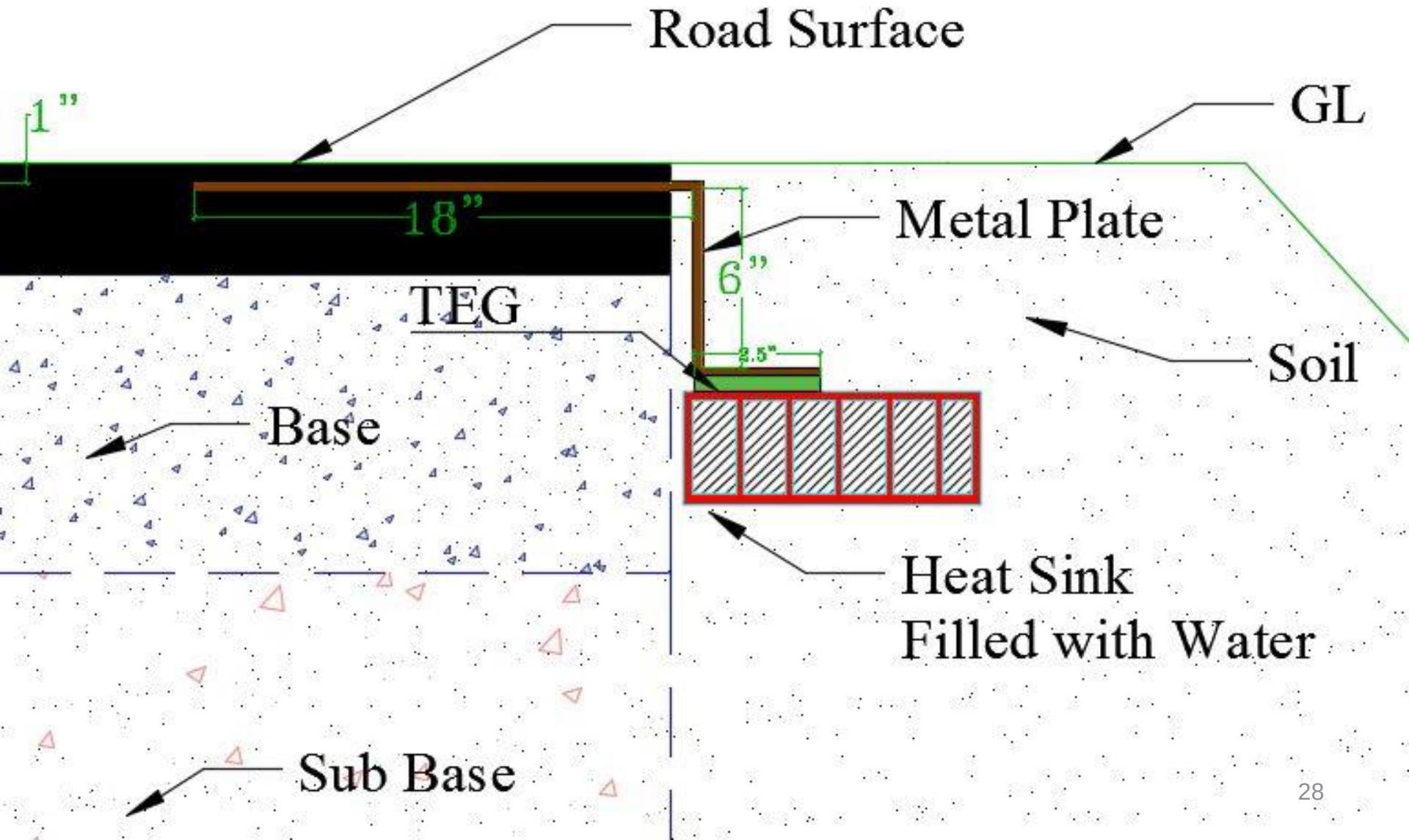
source: B. Matić, D. Matić, Đ. Ćosić, S. Sremac, G. Tepić, P. Ranitovic" A Model For The Pavement Temperature Prediction At Specified Depth" Issn 0543-5846,udc – Udk 62.001.57:536.5:625.144=111

Pavement Surface Temperature profile



- Average pavement surface temperature ranges from **45 to 55 C eight hours/**day (except Mid November to Mid February)
- Average soil temperature ranges from **25 C to 30 C** below 6” adjacent to road side soil.
- Available average thermal gradient ΔT= **20 C to 25 C**

Thermo-electricity Generation System

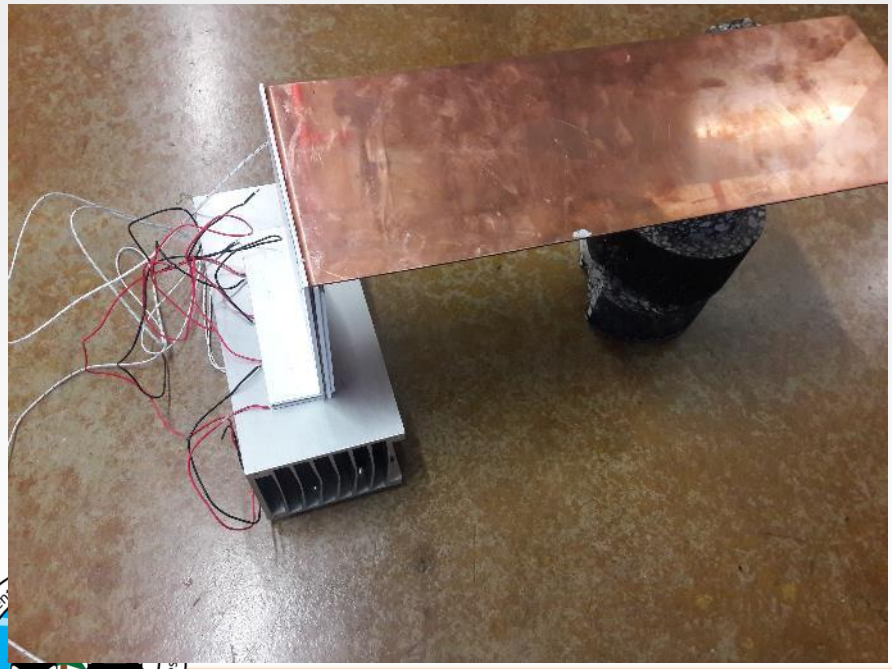


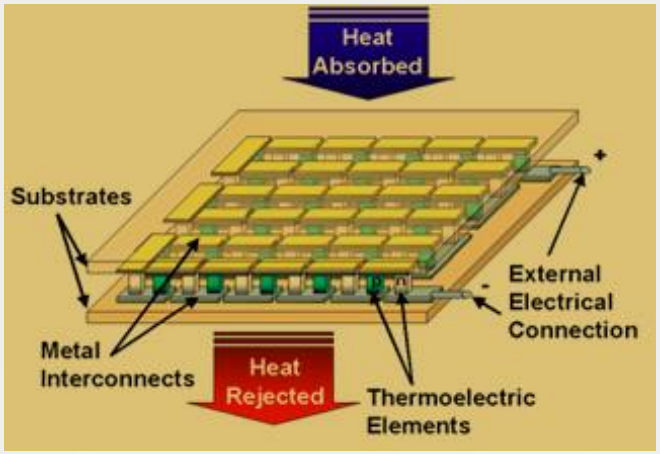
Thermo-electricity Generation System

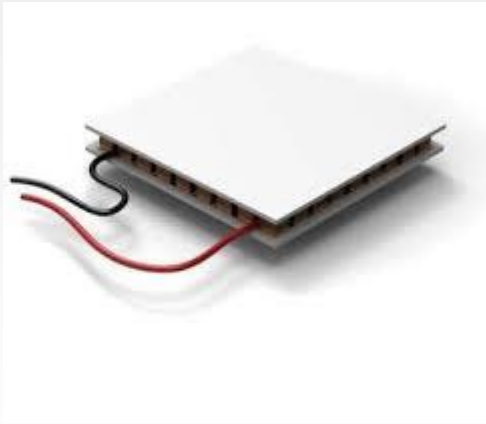
Thermoelectricity generation system: Harvests electrical energy from temperature gradient along pavement layers

Components

- Thermal Harvester
- Thermoelectric generator

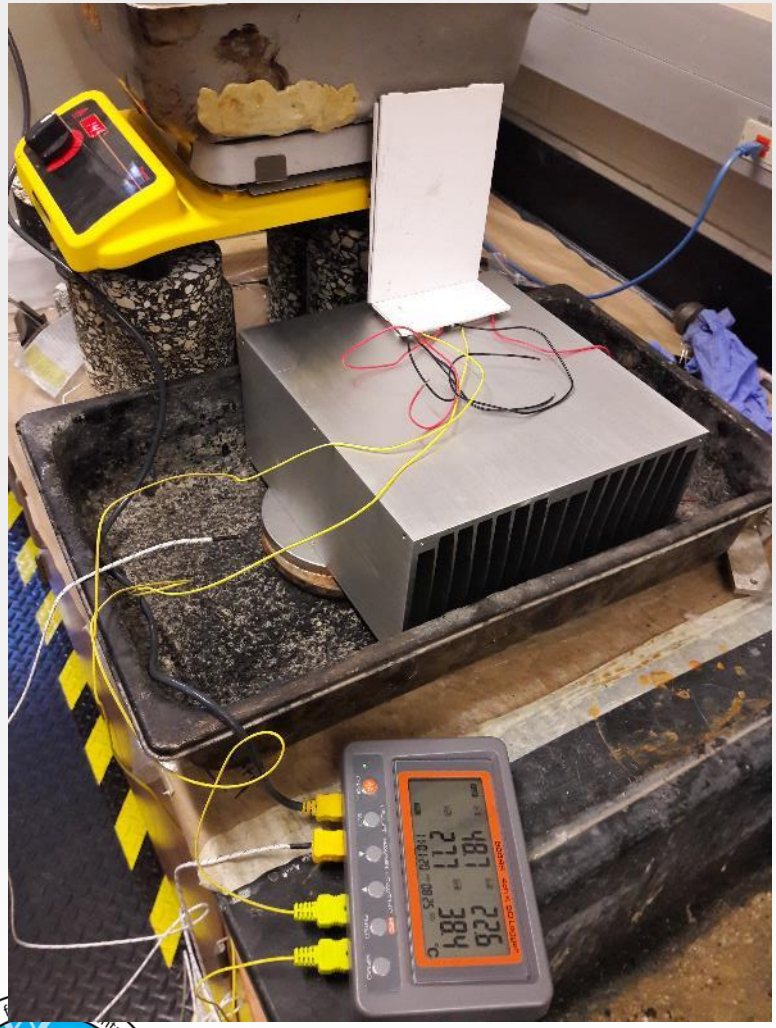


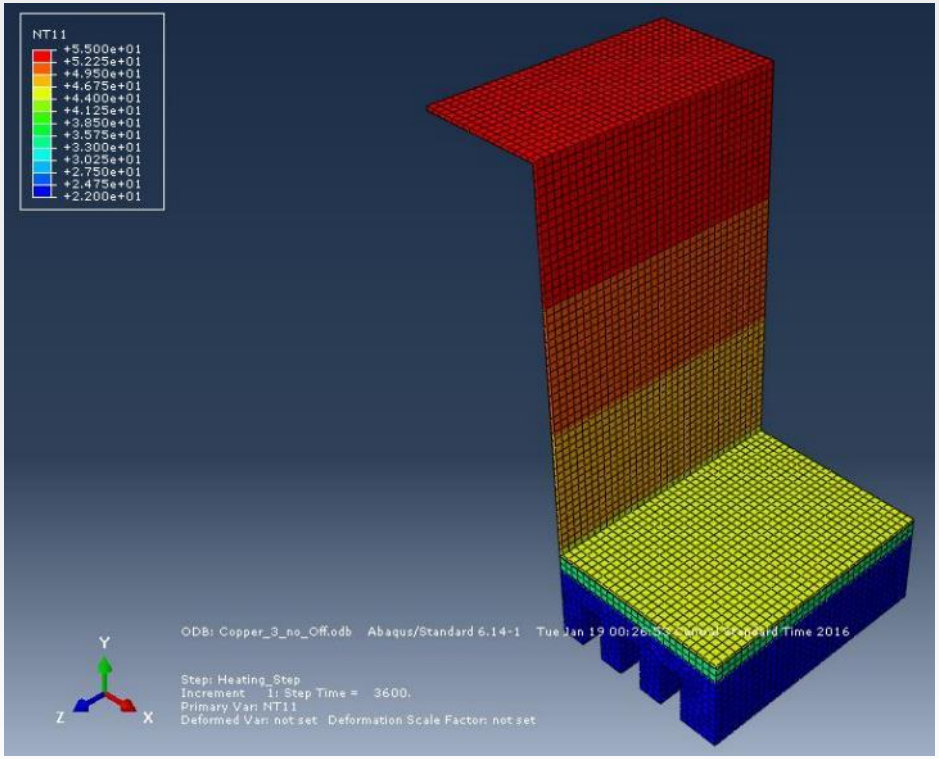




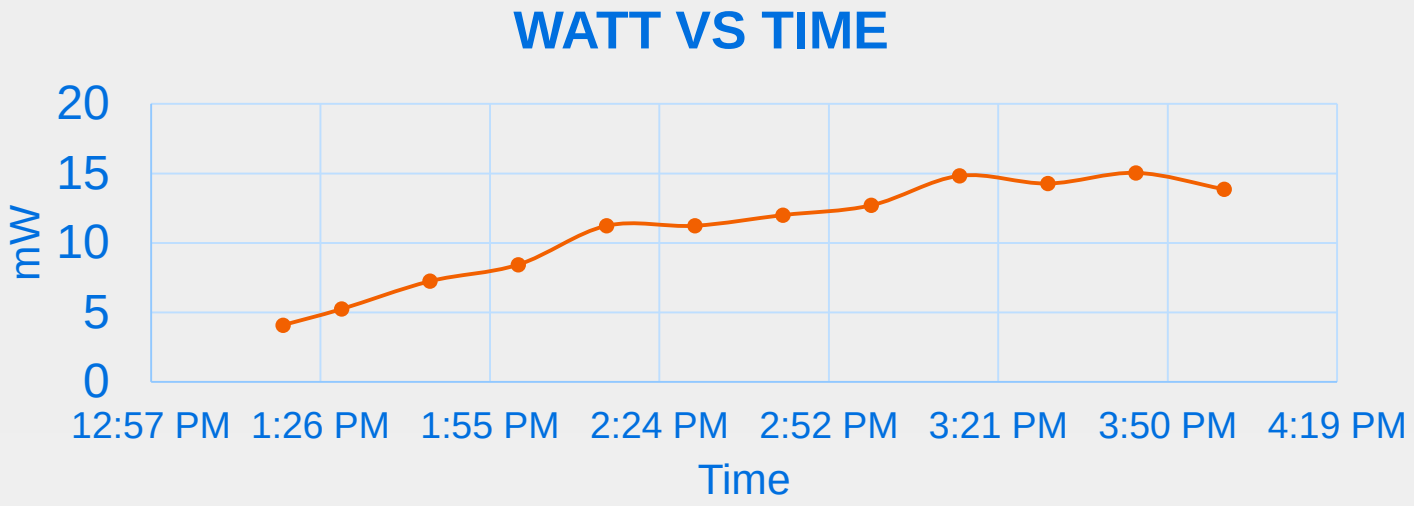
Thermoelectric module

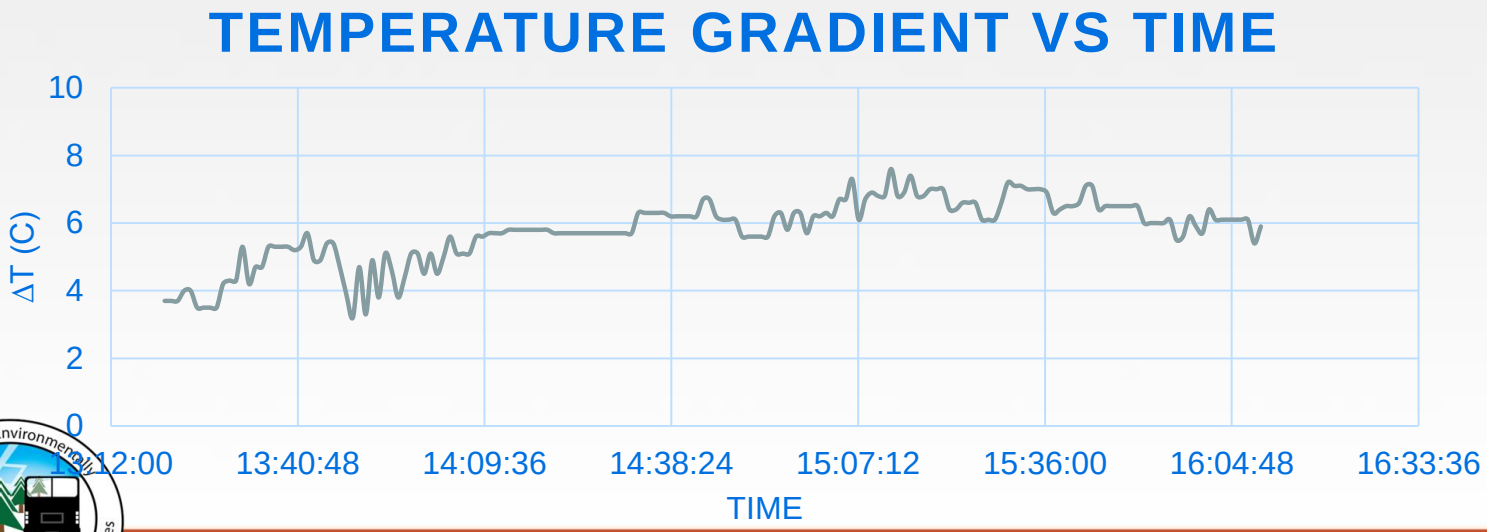
Finite Element Simulation and Lab Experiment





Real-time data collection and output analysis





First ASCE Innovation Contest in 2016

“*Most Innovative* in the category of Green Engineering”

Thank You