# Large-scale Evaluation of Pavement-attributed GHG Emissions from State Highway System Using PaveM and GIS Mapping

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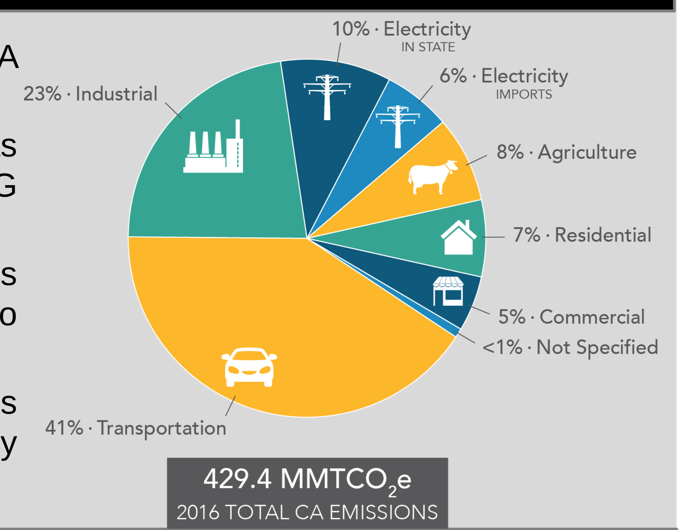
## INTRODUCTION

- The transportation sector constitutes 41% of all GHG emissions in CA (largest of all sectors); ~170 million metric tons of $CO_2$ equivalent ($CO_2$e).
- The needed pavement maintenance and rehabilitation (M&R) as well as vehicles operation are the main contributors to transportation- related GHG emissions.
- To be able to control and manage transportation-related GHG emissions (attributed to construction and traffic), the first and most important step is to be able to accurately quantifying these emissions.
- Senate Bill 32 (California Global Warming Solutions Act of 2006) requires CA to reduce statewide GHG emissions to 40% below the 1990 level by 2030.




## OBJECTIVES

- Utilize and enhance the Caltrans' pavement management system (PaveM) to evaluate and quantify GHG emissions attributed to pavements of the State Highway System (SHS) over the next 30 years in the two major stages:
  - Materials and Construction activities (M&C Stage)
  - Vehicles operation (Use Stage) influenced by rolling resistance (mainly IRI, deflection, and macrotexture).
- Evaluate effectiveness of pavement performance-based optimization algorithms in PaveM system used for project selection as means for controlling future GHG emissions.
- Evaluate effect of pavement repair spending plans on pavement-related GHG emissions quantities, repair costs, and energy (fuel) savings.
- Utilize GIS technology in mapping transportation-related GHG emissions quantities in both stages.

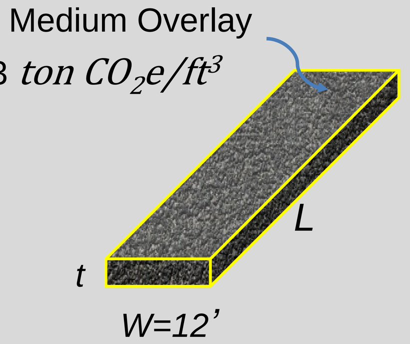
## METHODOLOGY AND BASELINE CALCULATIONS

### Calculating GHG Emissions: M&C Stage

e.g. Medium Overlay

$g\,(HMA)=0.006673\ ton\ CO_2e/ft^3$

$$GHG_{M\&C\ Stage} = \sum_l \sum_j (g_j \times t_j \times 12 \times 5280 \times L_j)_l$$



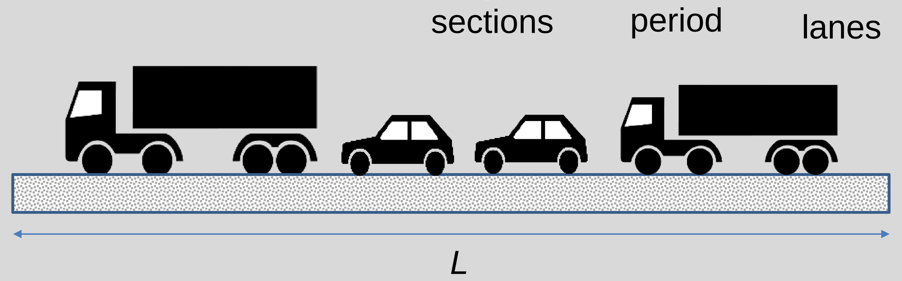

### Calculating GHG Emissions: Use Stage

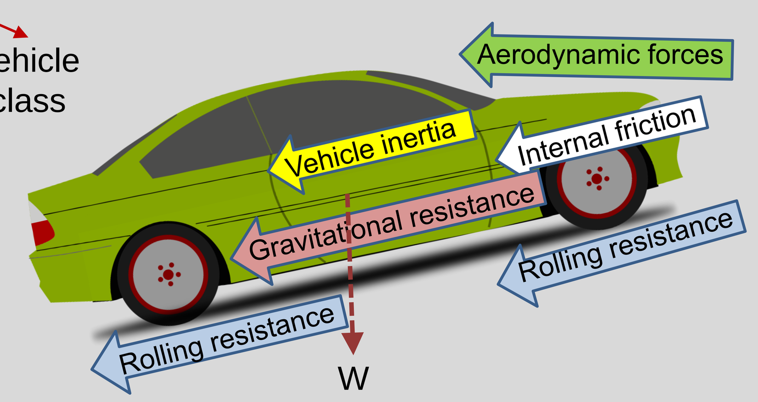
f: converts roughness to GHG emission due to rolling resistance (note effect of deflection and macrotexture incorporated in IRI).
C: converts roughness to GHG due to the other resistances.

Roughness factor · Constant · Volume of vehicle class · Section length

$$GHG_{vehicles}(IRI) = \sum_l \sum_k \sum_j \sum_i [(f_i \times IRI_k + C_i) \times V_{ij} \times L_j]_l$$

Management sections ($l$) · Analysis period ($k$) · Number of lanes ($j$) · vehicle class ($i$)




### Network current (2018) and "Ideal" GHG

j=vehicle classes, j=1-5
i=pavement management segments, i=1, 69,667

Network Master Data → $AADT_j$, $L_i$, $IRI_i$ → GHG-IRI models for each vehicle class

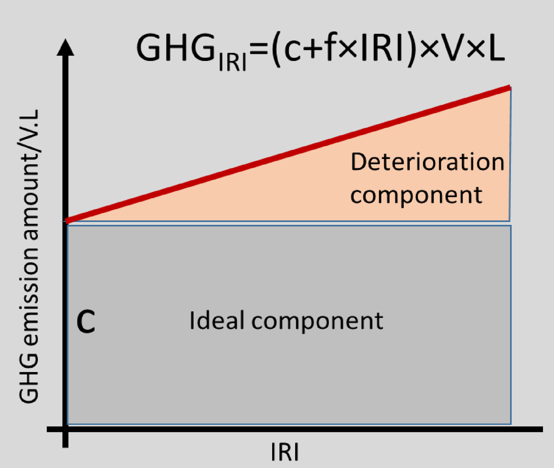
- Cars
- 2-axle trucks
- 3-axle trucks
- 4-axle trucks
- 5-axle trucks

Average IRI from APCS for each segment (fine segmentation)

**Current** (APCS date) GHG due to Use Phase **= 99.7 MMTCO$_2$e**

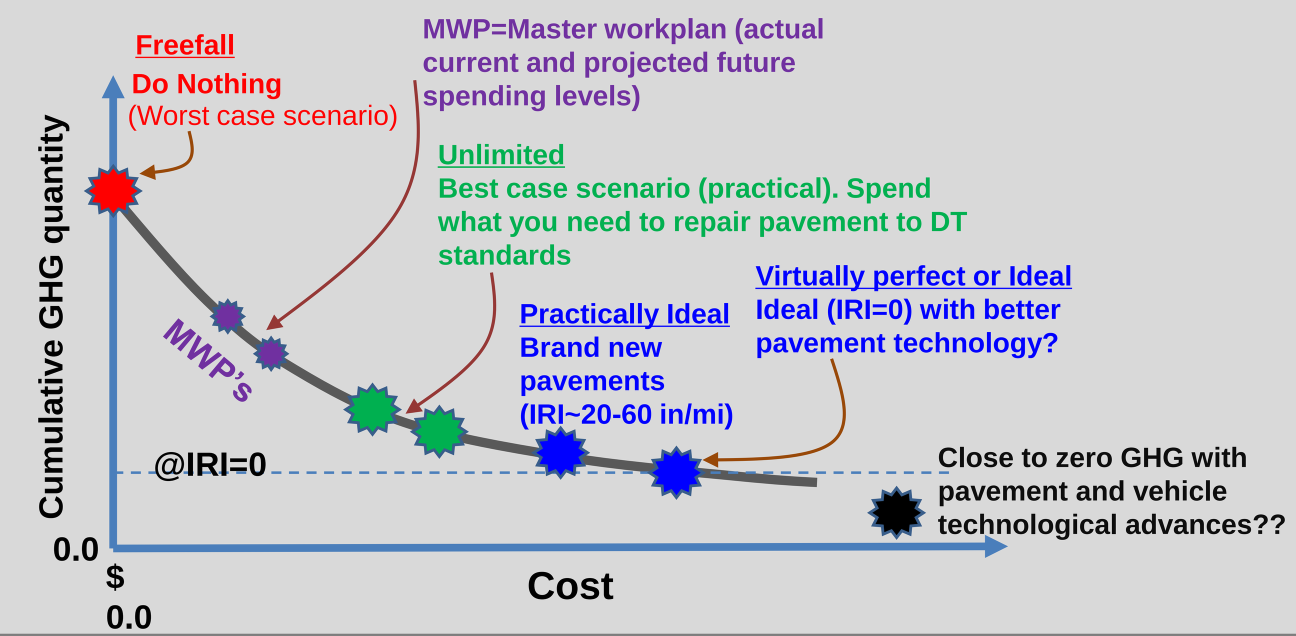
**Difference= 2.9 MMTCO$_2$e**

Replace every IRI value in Network Master File data with **IRI=0** to determine **Ideal** GHG for theoretically smoothest pavements **= 96.8 MMTCO$_2$e**



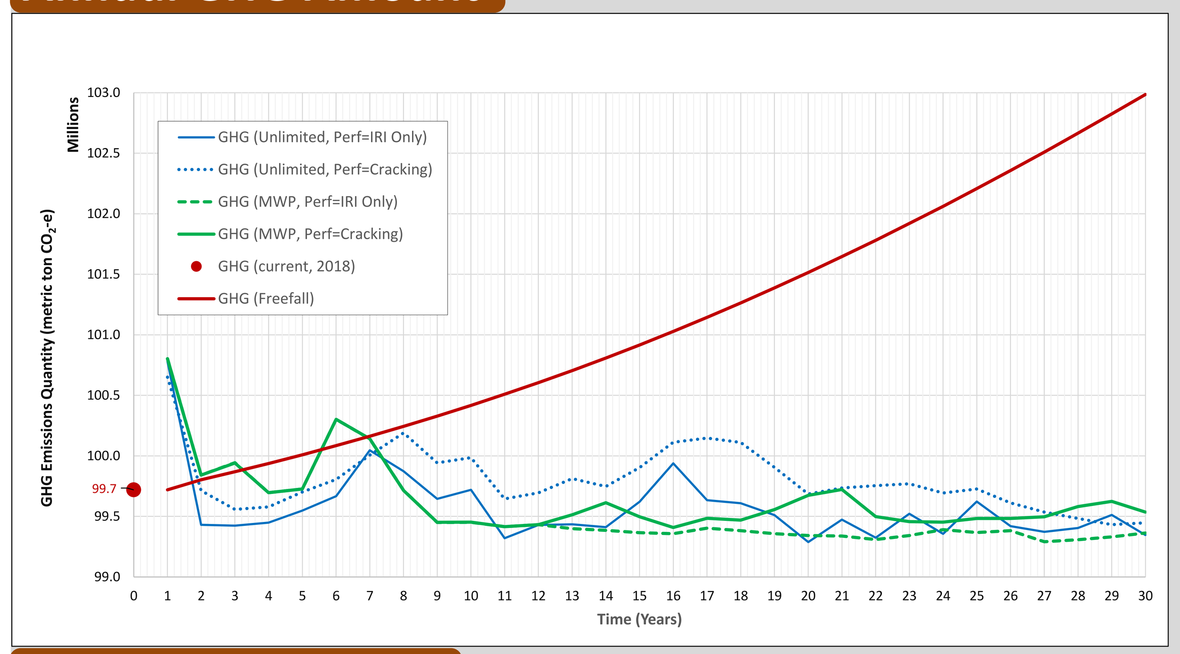

## PaveM Scenario Development

**Scenario #3357**: Freefall (Do Nothing)
**Scenario #3429**: Unlimited \$ (repair according to Decision Trees), Optimization objective="IRI Only"
**Scenario #3396**: Unlimited \$ (to repair network with Decision Tree), Optimization objective="Cracking"
**Scenario #3411**: Current & projected future funding levels (MWP), Optimization objective="IRI Only"
**Scenario #3410**: Current & projected future funding levels (MWP), Optimization objective="Cracking"

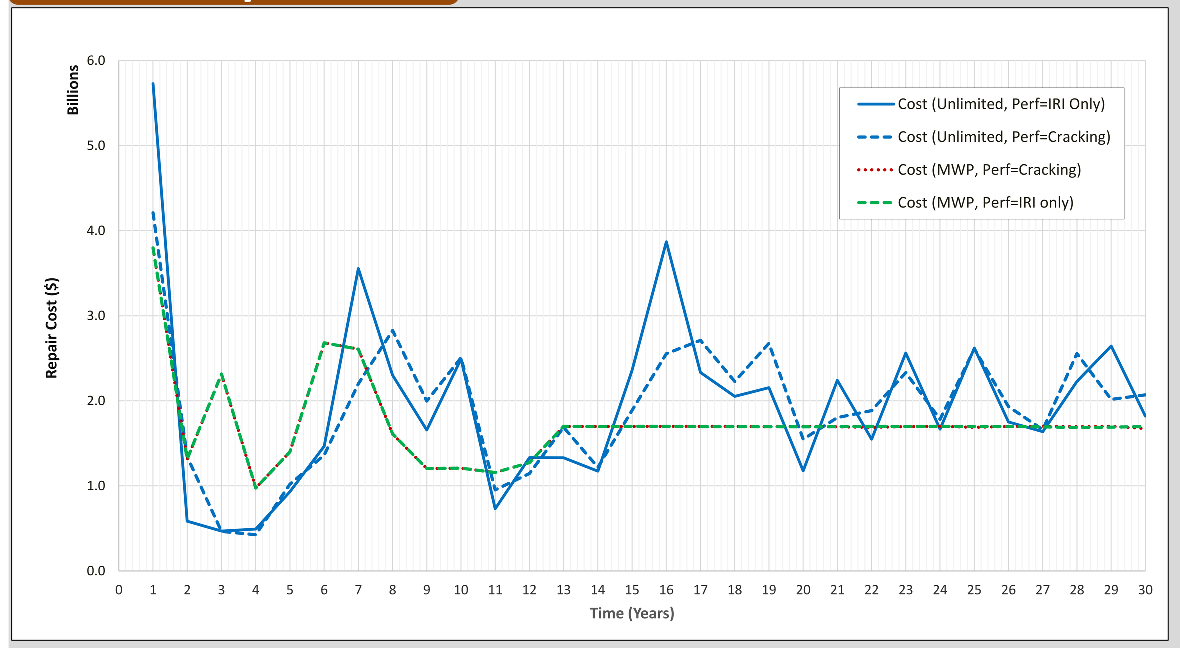



## RESULTS AND DISCUSSION

### Annual GHG Amount




### Annual Repair Cost




- Repair cost based on IRI as the optimization objective is only a little higher than based on cracking, but tremendous amounts of GHG emissions can be saved. Projects selection based on IRI results in lower GHG than on the basis of pavement cracking control due to Use Phase GHG being largely affected by IRI.
- GHG emissions for the freefall (do nothing) scenario increase rapidly over time. The annual GHG is much higher than when funds are expended based on either cracking or IRI as the performance criterion.
- The MWP scenarios are identical in the first 12 years because of preselected projects. Afterwards, the optimization objective (cracking vs. IRI) affects results (IRI based optimization leads to lower GHG than cracking based optimization). GHG amounts above freefall at any given year are due to repair related M&C GHG performed in that year.

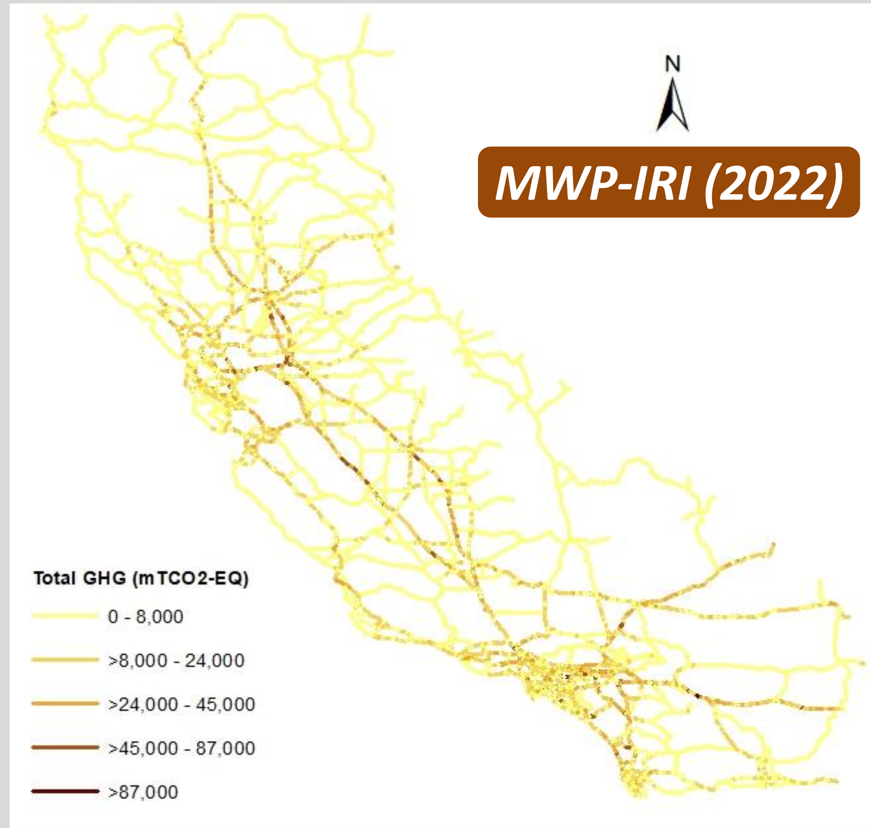
### 30-year Total GHG and Fuel Savings Summary

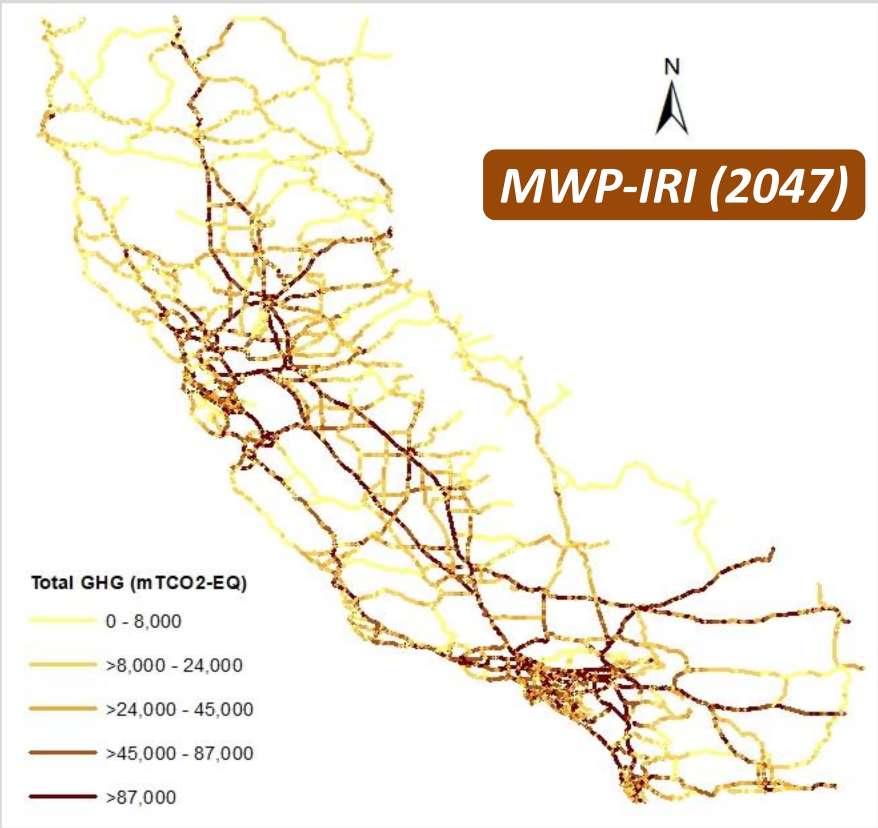
| Spending plan | Cumulative agency cost (\$ Billion) | Cumulative GHG saving (MMT) | Cumulative user saving in fuel cost (\$Billion) | Net cost (\$Billion) |
|---|---|---|---|---|
| MWP-IRI | \$52.08 | 47.08 | \$22.73 | \$29.36 |
| MWP-Cracking | \$52.07 | 43.95 | \$21.21 | \$30.86 |
| Unlimited-IRI | \$58.91 | 46.28 | \$21.72 | \$37.19 |
| Unlimited-Cracking | \$57.61 | 39.33 | \$18.64 | \$38.98 |
| Freefall | \$0.00 | 0.00 | N.A. | \$0.00 |
| Ideal case (IRI=0) | Not calculated | 129.01 | \$61.24 (correlation) | N.A. |

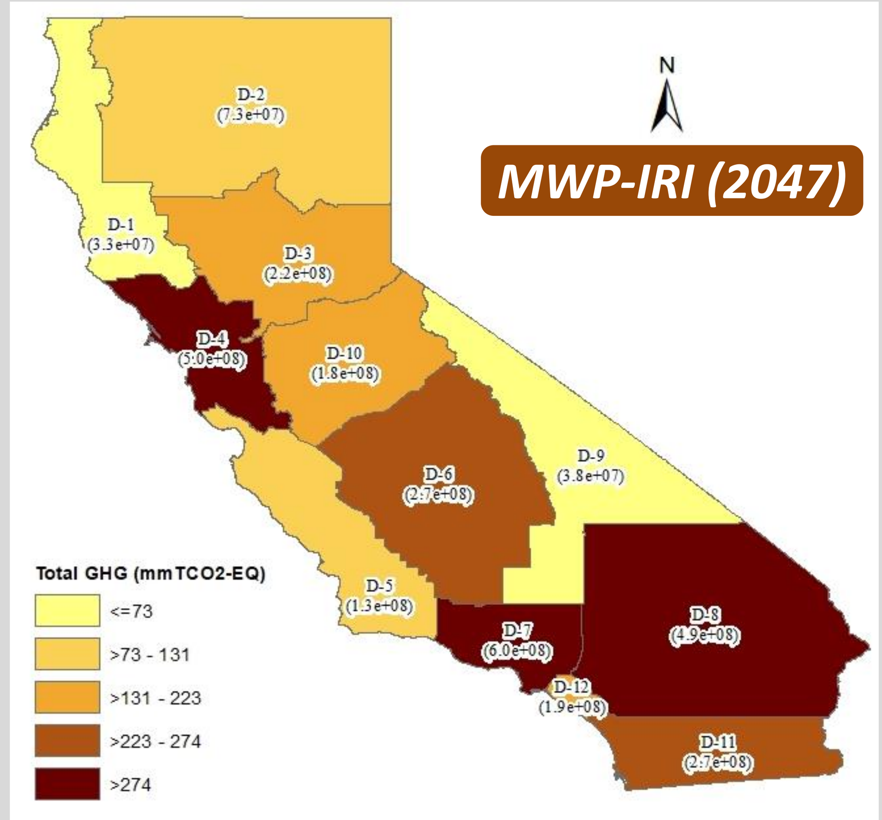
- Agency cost due to M&R cost.
- GHG saving relative to freefall.
- User cost savings in fuel cost due to vehicles operating on smoother pavements.
- Net cost is agency cost minus user savings in fuel cost.
- Selecting projects on the basis of "IRI benefits" leads to the greatest savings in BOTH fuel cost AND GHG emissions. It produces the lowest Net Cost.

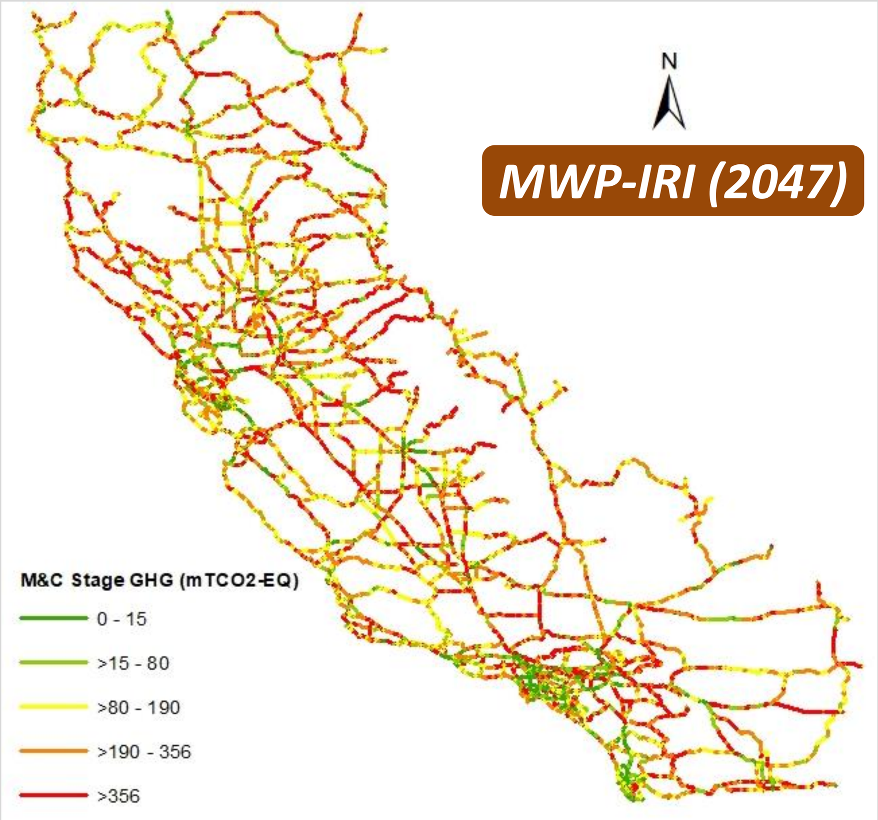
## GIS Mapping

A sample of GIS maps is presented for the MWP scenario at year 2022 for total GHG, and at year 2047 for total GHG and GHG due to M&C Stage. Also total GHG by districts at year 2047 is presented.




## CONCLUSIONS AND RECOMMENDATIONS

- A first large-scale study to accurately evaluate pavement-related GHG emission attributed to both M&C Stage and Use Stage that and implementing Caltrans' PaveM system run over ~70,000 pavement segments.
- The base year (2018) SHS GHG emissions quantity was calculated 99.7 MMTCO$_2$e; which is ~59% of estimated statewide total from transportation sector. Hypothetically, producing IRI=0 pavements would drop the SHS Use Stage GHG quantity to 96.8 MMTCO$_2$e.
- Several spending plans including Freefall (Do Nothing), Unlimited funding, and MWPs were evaluated and the effects of performance criteria on project selection in relation to GHG were studied.
- Interactive GIS maps have been developed to facilitate the visual presentation of GHG emissions quantities under various spending plans and over each highway segment. Totals per districts were also mapped.
- Project selection based on controlling IRI is equivalent to project selection on basis of minimizing GHG emission. Only for a small cost increase, SHS pavement repair on the basis of selecting projects that have greater impact on ride quality reduces 30-year cumulative GHG a lot greater than when projects are selected to control cracking.
- The M&C Stage related GHG is small compared to Use Stage GHG; and accounted to ~0.5% of total GHG.
- Districts 4, 7 & 8 contribute to ~53% of the SHS pavement carbon footprint. This is due to greater traffic and more lane miles (higher VMT). The greater number of lane-miles and higher traffic also contribute to more projects which also increase M&C Stage GHG.
- This study can help Caltrans manage pavements in such a way to minimize both the future cost to taxpayer and pavement carbon footprint.
- No change in traffic was assumed over the analysis period; which can affect predicted GHG. Determining traffic growth factors is rather complex as it must include predicting future technological improvements to vehicle technology and transportation models; which both depend on (or will influence) governmental policies!