



# Lifecycle Environmental Impact of High-Speed Rail System in the I-45 Corridor

## STAKEHOLDERS MEETING

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# Meeting Objective



- Discuss the context for HSR environmental study,
- Present findings and discuss the implication for Dallas-Houston region,
- Discuss recommendations,
- Assess the role of HSR system in alleviating persistent air quality problems in the nonattainment areas of Houston and Dallas,
- Reach consensus on the importance of HSR implementation,
- Request improvements to the environmental study and determine desired performance for the Dallas-Houston HSR system.





# Presentation Outline



- Background
- Objectives
- Methodology
- Results
- Conclusions
- Recommendations
- Acknowledgements

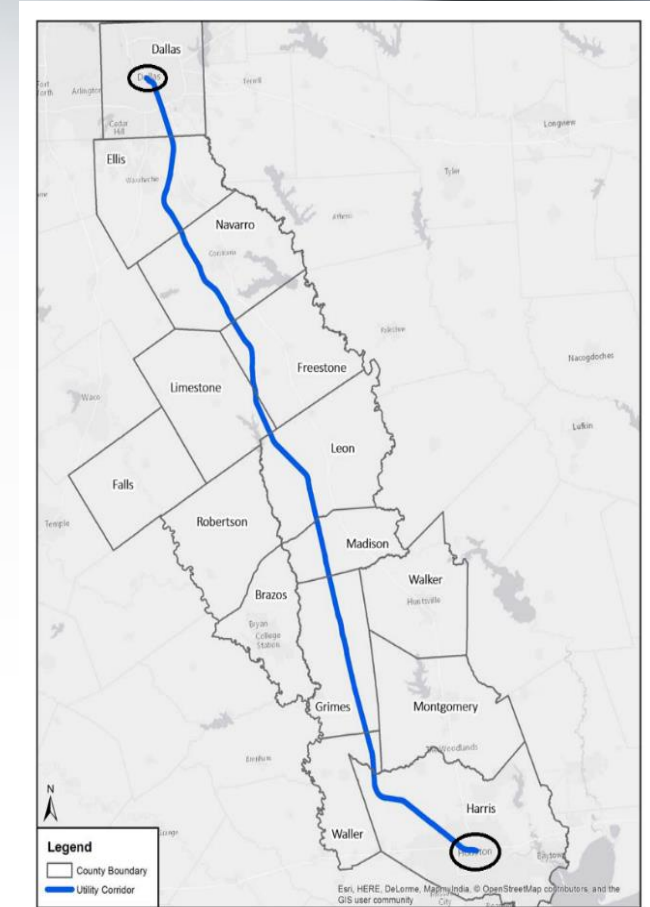




# Background



- Interstate 45 (I-45) highway connects the 4<sup>th</sup> and 5<sup>th</sup> largest metropolitan areas of the U.S., (Houston and Dallas),
- It connects the Gulf Coast, to domestic markets in Texas,
- Annual average daily traffic (AADT) volume is as high as 314,000 in 2016 [1, 2]
- Texas A&M Transportation Institute (TTI) studied (2009) the potential for development of Intercity Passenger Transit System in 18 corridors of Texas and ranked the Houston to Dallas corridor as the highest priority route in state of Texas [3]



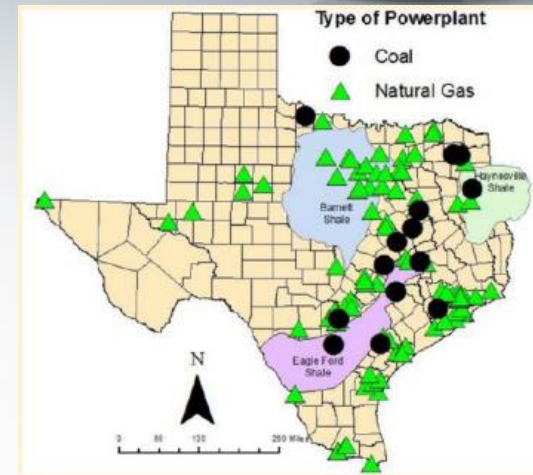
**Houston-Dallas HSR Utility Corridor**



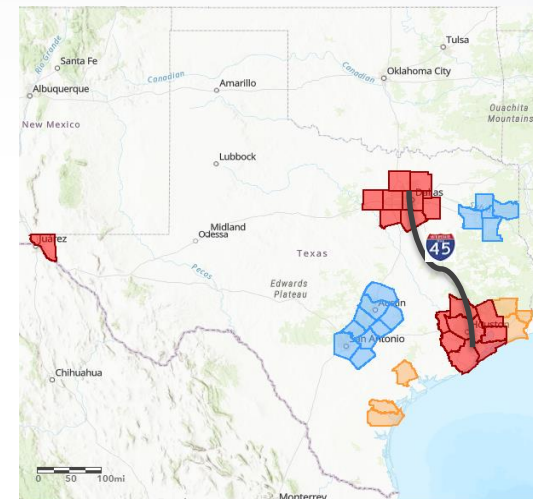
# Background



- Most of electricity generation power plants are located within the Texas triangle region.
- Texas triangle has the highest estimate population growth,
- Dallas and Houston are the two cities with the most non-attained counties, in Texas,
- The city councils of Dallas and Houston have recently taken steps toward the construction of a 240-mile HSR system to connect Dallas and Houston;
- HSR system have minimal release of regulated air pollutant and GHG [6], [7], [9-11]. This could:
  - Immensely benefit air quality in the nonattainment areas of Houston and Dallas, and
  - Mitigate the demand in mobility in the i-45 corridor



Source: Pacsi et al., 2013 [8]



Source: argis.com



# Rationale



- A cumulative assessment of the overall environmental impact from the proposed HSR system requires a life cycle assessment (LCA) study
- LCA accounts for all emissions generated over its lifetime, including phases such as raw material extraction and processing, manufacturing and construction, operation & maintenance and end of life.
- LCA is one of the most effective methods to estimate the environmental impact and evaluate the mitigation methods and technologies [4]





# Literature



- Miyauchi et al. (1999) conducted a basic LCA survey by comparing three HSR vehicles where most of impact was attributed to vehicle operation [5]
- Yue et al. (2015) advanced this research by including manufacturing, construction, operation and disposal of vehicle and infrastructure material **without including the impact of transportation phase** [6]
- Chester and Horvath (2010) who found contribution of emissions from operation phase in the range of 70-90% [7]





# Objectives



- (i) Develop the framework for methodological environmental LCA of current/proposed HSR corridors in south-central US
- (ii) Estimate the net change in GHG emissions and global warming potential (CO<sub>2</sub>eq) due to the Houston-Dallas HSR system from a lifecycle perspective
- (iii) Compare the improvements in sustainability resulting from the HSR system under varying degrees of traffic migration/passenger adoption from existing transportation modes
- (iv) Analyze the effect of source electricity mix scenarios on the environmental impacts from the operation phase of the proposed HSR system (not presented here)



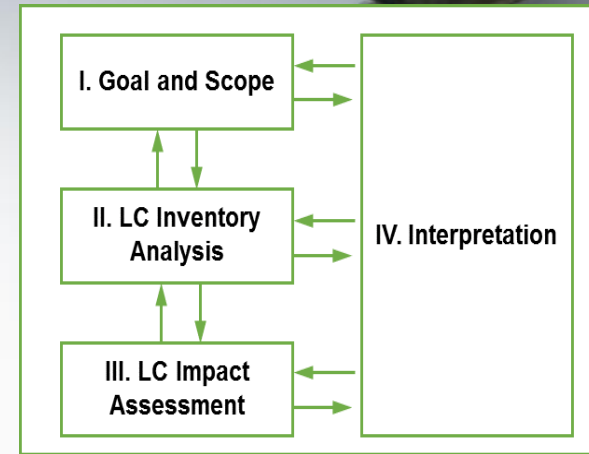




# Methodology



- ▶ A Life Cycle Assessment performed using SimaPro 8.3 and Ecoinvent 3.3
- ▶ Goal and scope: estimates the environmental impact resulting from the total life cycle of the HSR system. The environmental scope includes criteria air pollutants-CAPs, GHGs, and energy consumption,
- ▶ Life-cycle inventory: investigated peer-review publications, technical reports and documents/databases impact analysis, etc.,
- ▶ Conducted Life Cycle Impact Assessment using Impact 2002+ and single score methodology.
- ▶ Results' interpretation: Identify methodological issues associated with inventory data and impact category; select and evaluate opportunities to reduce HSR system environmental impacts.



Four Phases of LCA



# Methodology



- This life cycle study was conducted as per the framework and procedures of ISO 14040 and ISO 14041
- The HSR system analysis was divided into two main sub-systems (Vehicle, Infrastructure)



Photos from Houston Chronicles

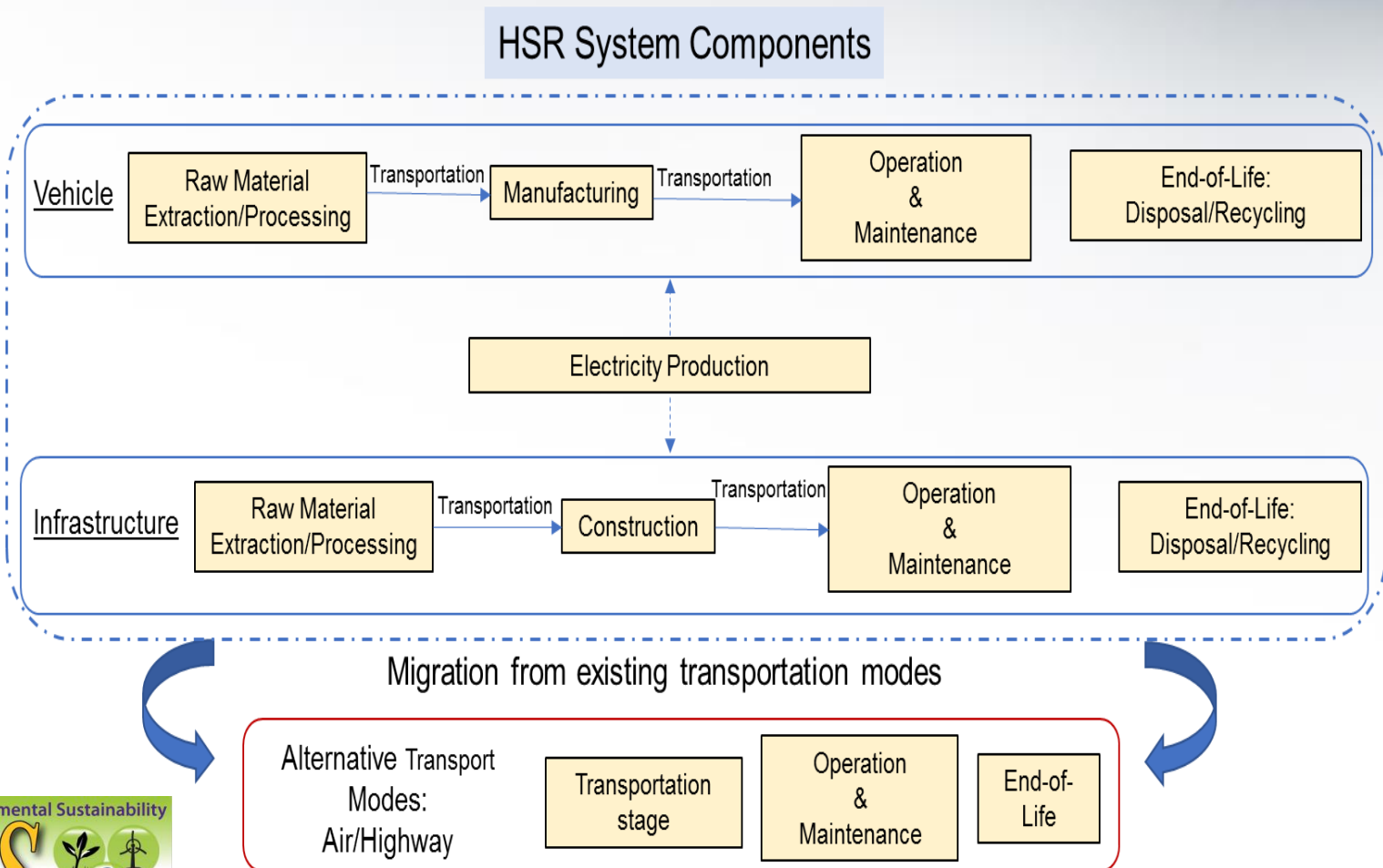




# Methodology



## Description of a complete life cycle model design and system boundary (in dotted lines)







# Methodology



- ▶ The inventory base case begins with ecoinvent v3 process for transportation services, adjusted to reflect the actual conditions for Dallas-Houston HSR system.
- ▶ Other specific data such as electricity mix for operation phase, distance, material and energy were also included to reflect the number of maintenance services along the Dallas-Houston corridor.
- ▶ The alternative mode (road and air) of transportation includes vehicle/aircraft lifetime correspondent to fuel amount in passenger kilometers traveled. All modules account for emissions during manufacturing, operation and maintenance, and the infrastructure constructions of each system.
- ▶ Current conditions: 89% of passenger volume in this route is car at 1.2 passengers/car; Aircraft is ~9% and bus ~2%



# Methodology



- *Mid point categories are chosen to report the findings rather than end point categories*
- *Mid point categories give emissions/releases (causes)*  
Vs  
*End point categories which give effects*
- *Study goal is to find Criteria Air Pollutant (CAP) emissions (more specifically Ozone precursors ) which is the major issue for these two non-attainment areas)*





# Methodology



- The functional units used for this study are Vehicle Kilometers Traveled (VKT), and Passenger Kilometers Traveled (PKT).
- Equation 1 expresses the calculation for individual system's emissions, where  $E$  is the emissions of pollutant in Vehicle Kilometers Traveled (VKT) per year;  $TE_i$  is Total life time emission of a given pollutant; and  $D_t$  is Total lifetime distance traveled (km/years).

$$E(VKT) = \frac{TE_i}{D_t} \quad (1)$$

LCIA Method: Impact 2002+  
LCA Software: SimaPro 8.3  
Midpoint Categories (15)

7 Japanese Shinkansen N700 trains  
Each with 8 cars and 400 passenger capacity



# Methodology



- Quantification of midpoint results presented as Passenger Kilometers Traveled (PKT) (Equations 2 & 3).
- Percentage distribution at midpoint were normalized to reflect the lifetime of vehicle (20 years) and infrastructure (60 years).

$$E_{Vehicle} = \frac{Q_{Vehicle}}{p \cdot d \cdot R \cdot Y_{Vehicle}} \quad (2)$$

$$E_{Infrastructure} = \frac{Q_{Infrastructure}}{p \cdot d \cdot R \cdot Y_{Infrastructure}} \quad (3)$$

## Conditions

$E_{vehicle}$  (PKT) = Vehicle emissions per Person Kilometers Traveled;

$E_{infrastructure}$  (PKT) = Infrastructure emissions per Person Kilometers Traveled;

Q= lifetime emission of a given pollutant;

p = person (seat);

R= vehicle utilization rate;

$Y_{Vehicle}$  = Years of operation

$Y_{Infrastructure}$  = Years of operation.

d = distance (DAL-HOU)





# Assumptions



- Due to lack of information on the Japan's vehicle inventory this assessment considers similar trains manufactured in Germany, for which inventory is available in the ecoinvent database (Yue Ye et al. 2015)
- The LCA inventory is built based on the Dallas-Houston HSR Environmental Impact Statement Report sponsored by the Department of Transportation and by the Texas Central Railroad (TCRR)
- The SimaPro processes include inputs of raw materials, energy used and onsite transportation of product.
- The HSR track choice is a non-ballast, with viaducts and bridges, above the threshold level, avoiding interference with the existing transportation system.
- The end-to-end route distance was estimated to be approximately 384.63 kilometers operated at the speed of 329.91 Km/h.





# Results – Midpoint Impacts



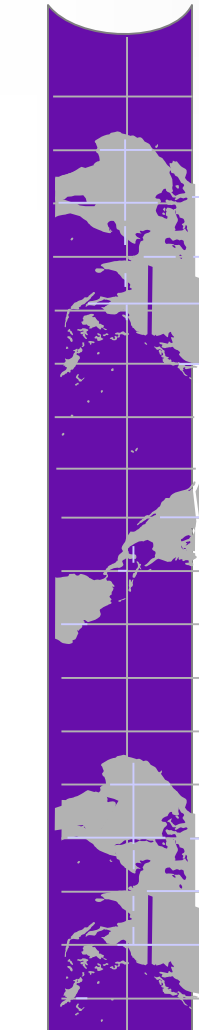
## Midpoint Impacts and relative contribution of vehicle and infrastructure

	Impact category	Unit	Total Quantity	Vehicle <sup>1</sup>	Infrastructure <sup>2</sup>
a	Carcinogens	kg C <sub>2</sub> H <sub>3</sub> Cl eq	1.49E+08	62.64%	37.36%
b	Non-carcinogens	kg C <sub>2</sub> H <sub>3</sub> Cl eq	4.66E+08	40.22%	59.78%
c	Respiratory inorganics	kg PM <sub>2.5</sub> eq	17056764	<b>95.85%</b>	4.15%
d	Ionizing radiation	Bq C-14 eq	5.53E+10	<b>97.99%</b>	2.01%
e	Ozone layer depletion	kg CFC-11 eq	1250.64	51.69%	48.31%
f	Respiratory organics	kg C <sub>2</sub> H <sub>4</sub> eq	1990505.20	66.26%	33.74%
g	Aquatic ecotoxicity	kg TEG water	1.09E+12	65.52%	34.48%
h	Terrestrial ecotoxicity	kg TEG soil	3.77E+11	56.09%	43.91%
i	Terrestrial acid/nutri	kg SO <sub>2</sub> eq	1.17E+08	83.77%	16.23%
j	Land occupation	m <sup>2</sup> org.arable	2.07E+08	34.48%	65.52%
k	Aquatic acidification	kg SO <sub>2</sub> eq	40190998	84.13%	15.87%
l	Aquatic eutrophication	kg PO <sub>4</sub> P-lim	9049321.90	74.63%	25.37%
m	Global warming	kg CO <sub>2</sub> eq	5.66E+09	<b>92.77%</b>	7.23%
n	Non-renewable energy	MJ primary	7.87E+10	<b>92.83%</b>	7.17%
o	Mineral extraction	MJ surplus	4.02E+09	18.63%	81.37%

### Notes:

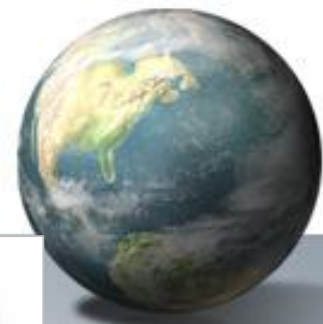
<sup>1</sup>emissions were estimated for 20 years of vehicle lifetime, and;

<sup>2</sup> Infrastructure at 60 years lifetime.

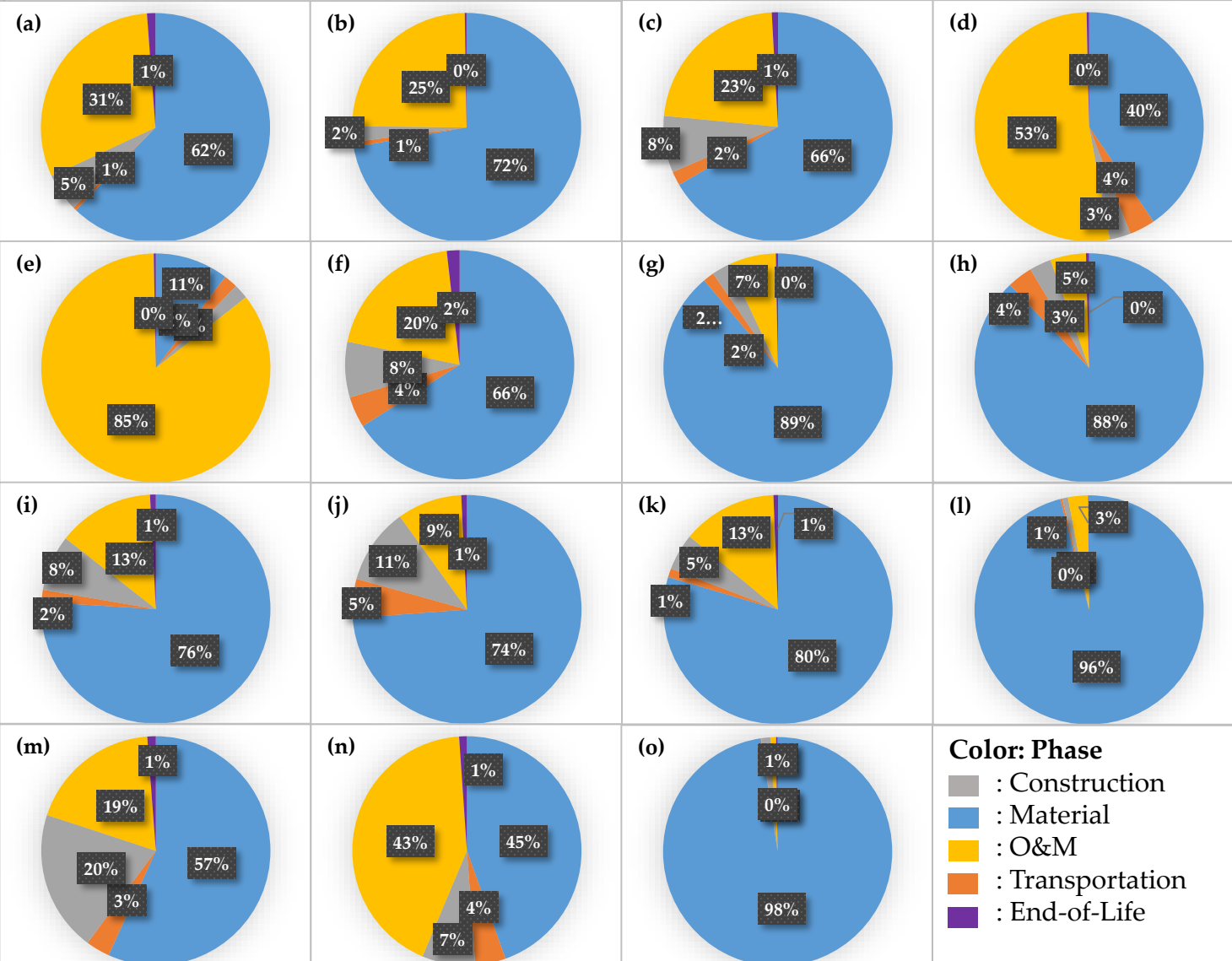




# Results – Phase Contributions



Distribution of phase-wise midpoint impact for infrastructure



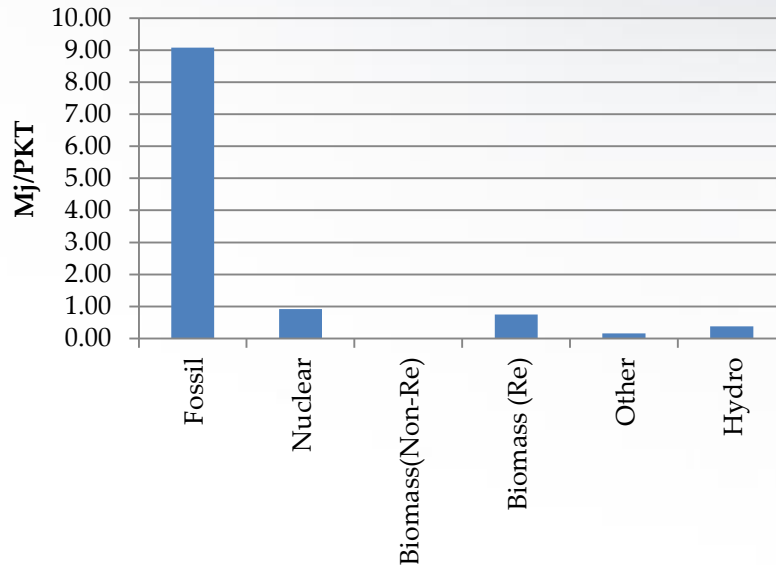
**Color: Phase**  
 ■ : Construction  
 ■ : Material  
 ■ : O&M  
 ■ : Transportation  
 ■ : End-of-Life



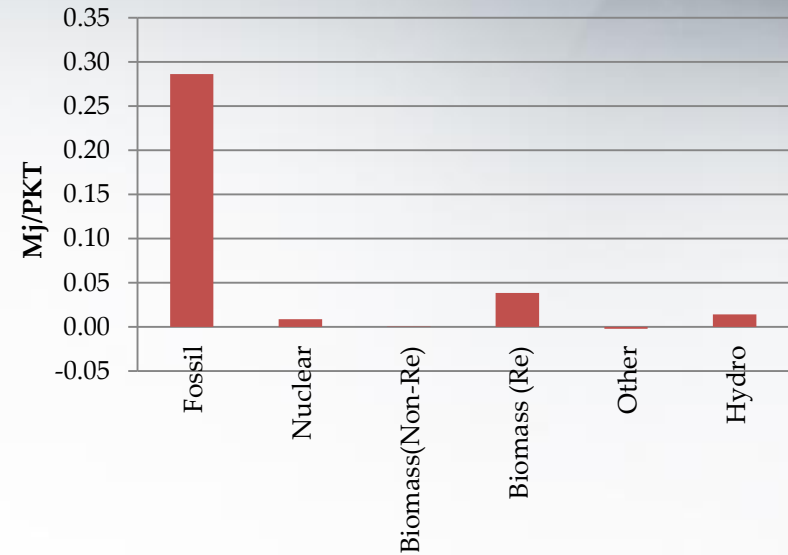
# Results – Energy Demands



(a) Vehicle



(b) Infrastructure

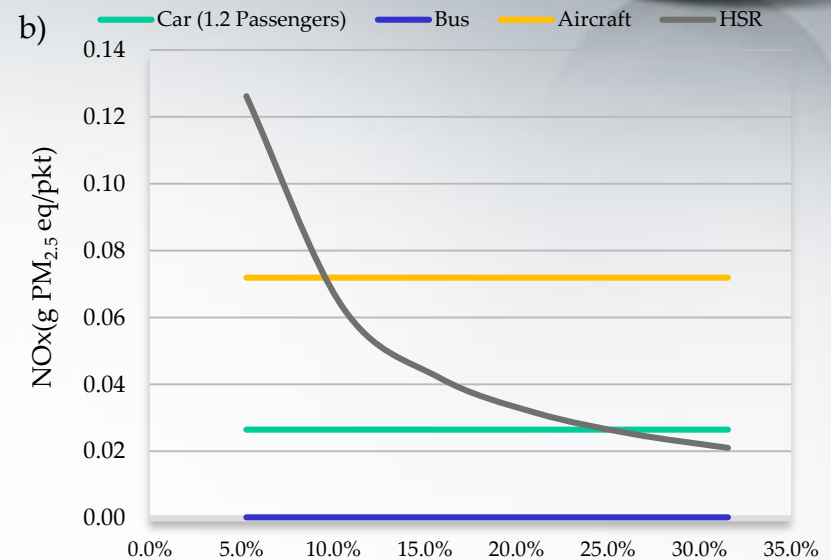
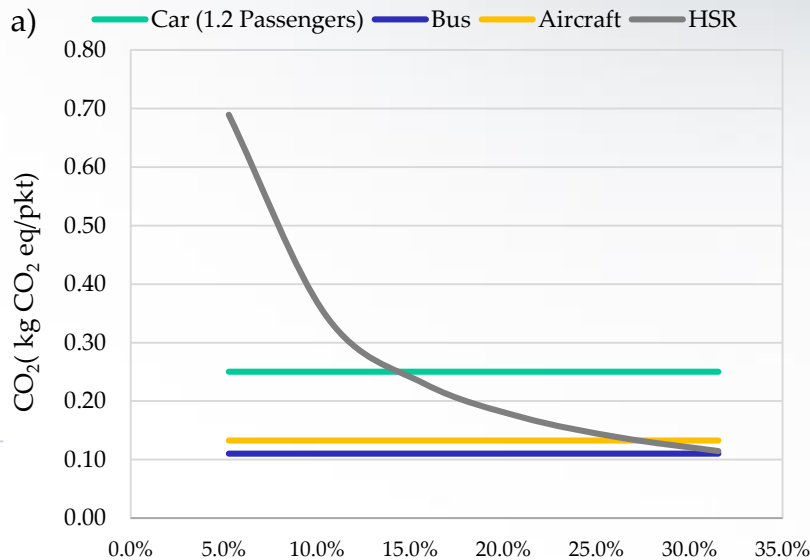


Other energies: Wind, solar, geothermal

Cumulative Energy Demand for Vehicle and Infrastructure at 70% ridership.



# Results – Effect of Ridership

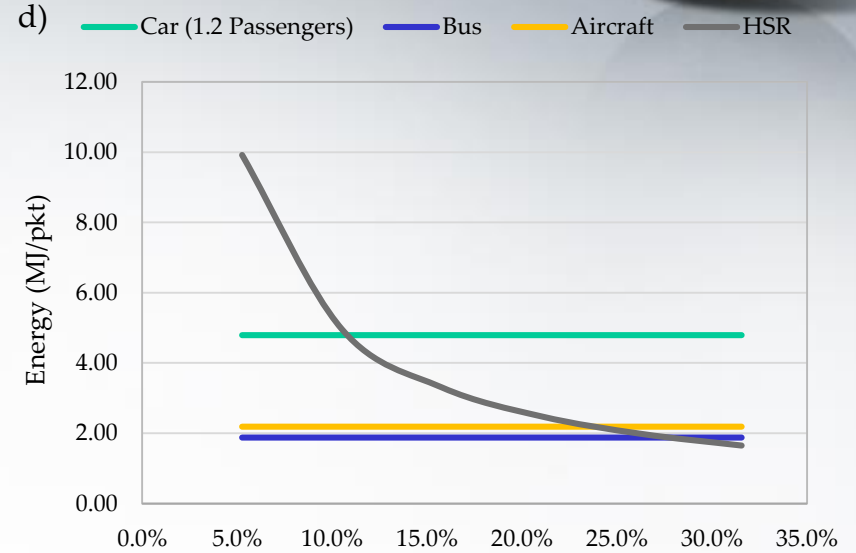
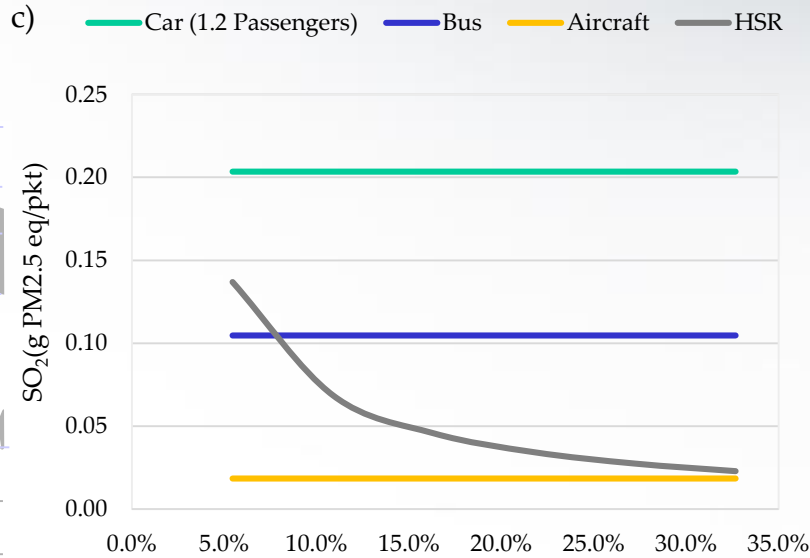


Effect of ridership levels on environmental efficacy of various categories

(a) Global Warming Potential (b) NOx



# Results – Effect of Ridership

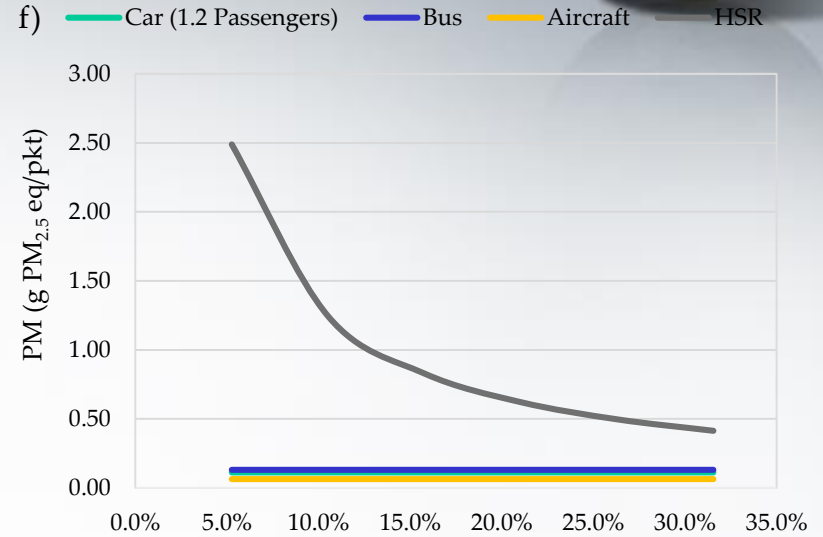
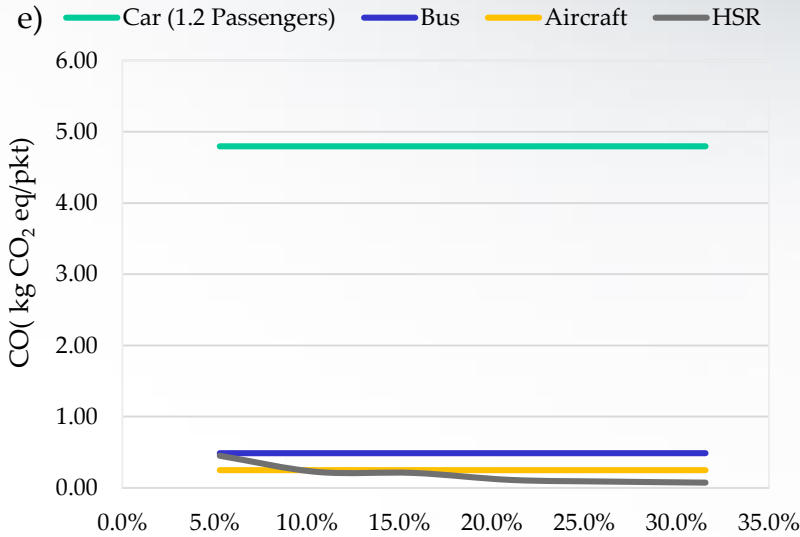


Effect of ridership levels on environmental efficacy of various categories

(c) SO<sub>2</sub>; (d) Total Energy



# Results – Effect of Ridership



Effect of ridership levels on environmental efficacy of various categories

(e) CO; (f) PM



# Results – Sensitivity Analyses



- Evaluate the environmental benefits resulting from the change in the source electricity mix:
  - Operation and maintenance contribute the most in the overall vehicle emissions, and;
  - Electricity mix is the main driver to the increases pollutant emissions.
- The current U.S. and Texas electricity mix do not reflect the actual SimaPro® inventory.
- The U.S SimaPro electricity mix has the highest share for electricity from coal and lignite
- The Electric Reliability Council of Texas (ERCOT) mix is mostly from gas sources







# Results – Sensitivity Analyses



The main vehicle emissions were assessed using the actual share of Texas and the U.S electricity, It was observed potential reduction in:

- CO<sub>2</sub> contribution by 64%,
- SO<sub>2</sub> by 78%, NO<sub>x</sub> by 60%
- N<sub>2</sub>O emissions by 57%.

The comparative analyze between HSR system and other transportation modes, and the sensitivity analyses of vehicle operation shows that Galveston-Dallas region benefits:

- By reducing CAPs and GHS emissions;
- Contributes to the air quality improvement in the region.





# Major Conclusions



- The midpoint impact category results for HSR system shows that vehicle operation is the major contributor to emissions and energy used.
- Vehicle accounts for 14.50 kgCO<sub>2</sub>eq/VKT, of which fossil-fuel usage where operation is the primary contributor with 98% of the GHG emissions.
- For the infrastructure, 56.76% of GHG emissions are contributed by the material extraction and processing phase (23.75 kgCO<sub>2</sub>eq/VKT).





# Major Conclusions



- The minimum ridership levels required to offset the environmental impact from conventional modes of transport, such as personal cars, bus and aircraft, are around 12% and 27% for GHG emissions and NOx emissions respectively.
- The increase in the percentage of renewable energy, in the train operation phase, will significantly reduce the impact of pollutants and GHGs emissions, in the region.
- The implementation of the HSR system, in the region, provides benefits in are of environmental, safety, time, and commodity of passengers traveling between Dallas –Houston.





# Recommendations



- Continue to educate the public to increase awareness of the environmental benefits of HSR.
- Increase of the occupancy rate will reduce the total environmental impact generated by construction of the HSR system. In addition, it will:
  - Reduce the population of passengers traveling by car can improve air quality along the i-45 corridor.
  - Passengers will use efficient transportation and save time, during rush hour.
- Improve mobility in the face of growth to mitigate population increase by 2050.
- Increase the use of renewable energy for HSR system operation.





# Acknowledgements



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# Questions/Comments



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