Development of a Greenhouse Gas Emission Inventory and Analysis of Emissions Reduction Strategies for Aviation

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Initial Statements

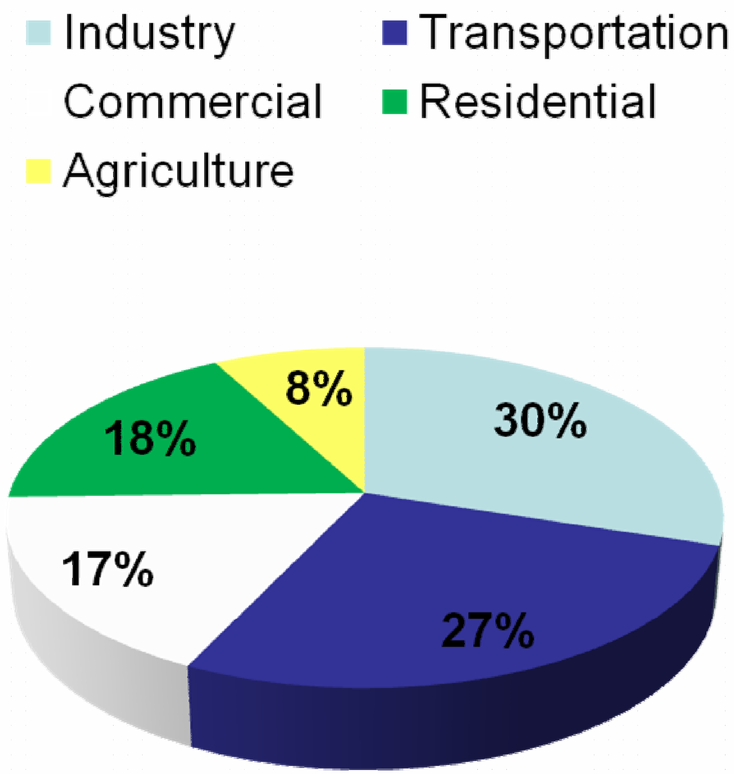
- I do see the irony in my flying across the country to discuss aviation CO_2 emissions
- Acknowledgements:
  - UCTC for their support of this research
  - ATAC Corporation for technical analysis support, data gathering, and enthusiasm for the project
  - Elaine & Irene Kwan and Piu-Wah Lee, 3 dedicated and spirited undergraduate researchers
  - NEXTOR Graduate Students for their ideas, skills, data, and general support while I refine my thesis topic

Aviation & Greenhouse Gas Reduction: Scenario Analysis

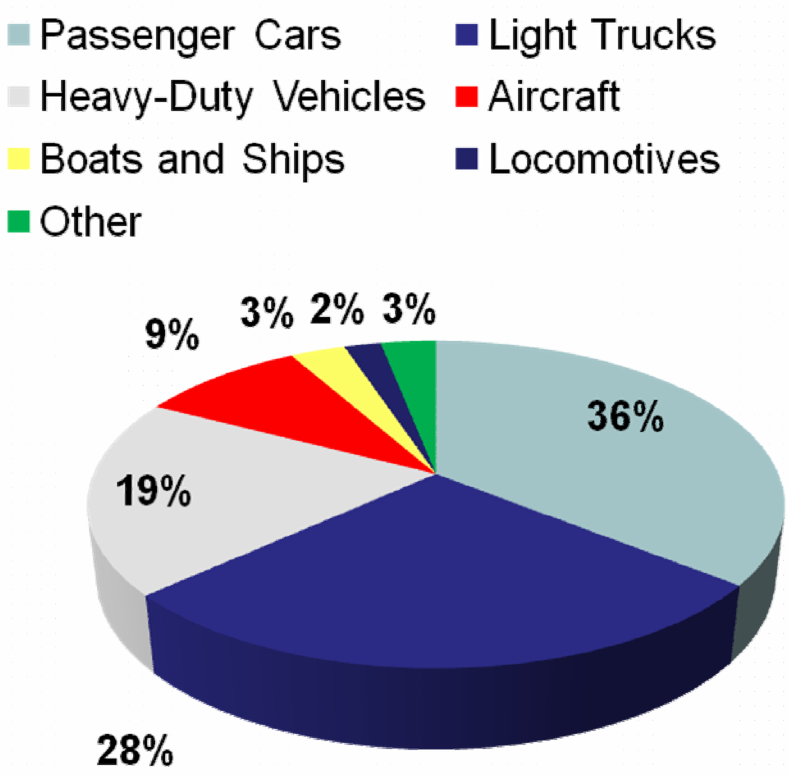
- Scenario: Aircraft operators must reduce CO_2 emissions by a certain percent
- Responses:
  - Purchase offsets/credits from another industry
  - Reduce aviation-related CO_2 emissions
- Purpose of analysis
  - What is the least expensive way to meet this CO_2 reduction target?
  - Does it make sense to reduce CO_2 from aviation?

Domestic CO_2 Emissions Profile

GHG Emissions by End-Use Sector (EPA, 2006)



Transportation GHG Emissions (EPA, 2006)



Research Outline

- Develop high-level aircraft CO_2 emissions model
- Define study corridor and develop baseline CO_2 emissions inventory
- Define a taxonomy of strategies
- Test different scenarios
  - Aircraft swap
  - Mode shift to auto
  - Airport-access mode shift to electric vehicles
- Discuss cost of CO_2 emission reduction

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Fuel Burn Model

- **Predicts fuel burn for a flight as a function of**
  - **Stage length**
  - **Number of seats**
  - **Average age of type**
- **Estimated from Form 41 Aircraft Operation Data**

Fuel Burn Model

All coefficients significant at 1% level

Regression Statistics	
Adjusted R Square	0.958
Observations	111

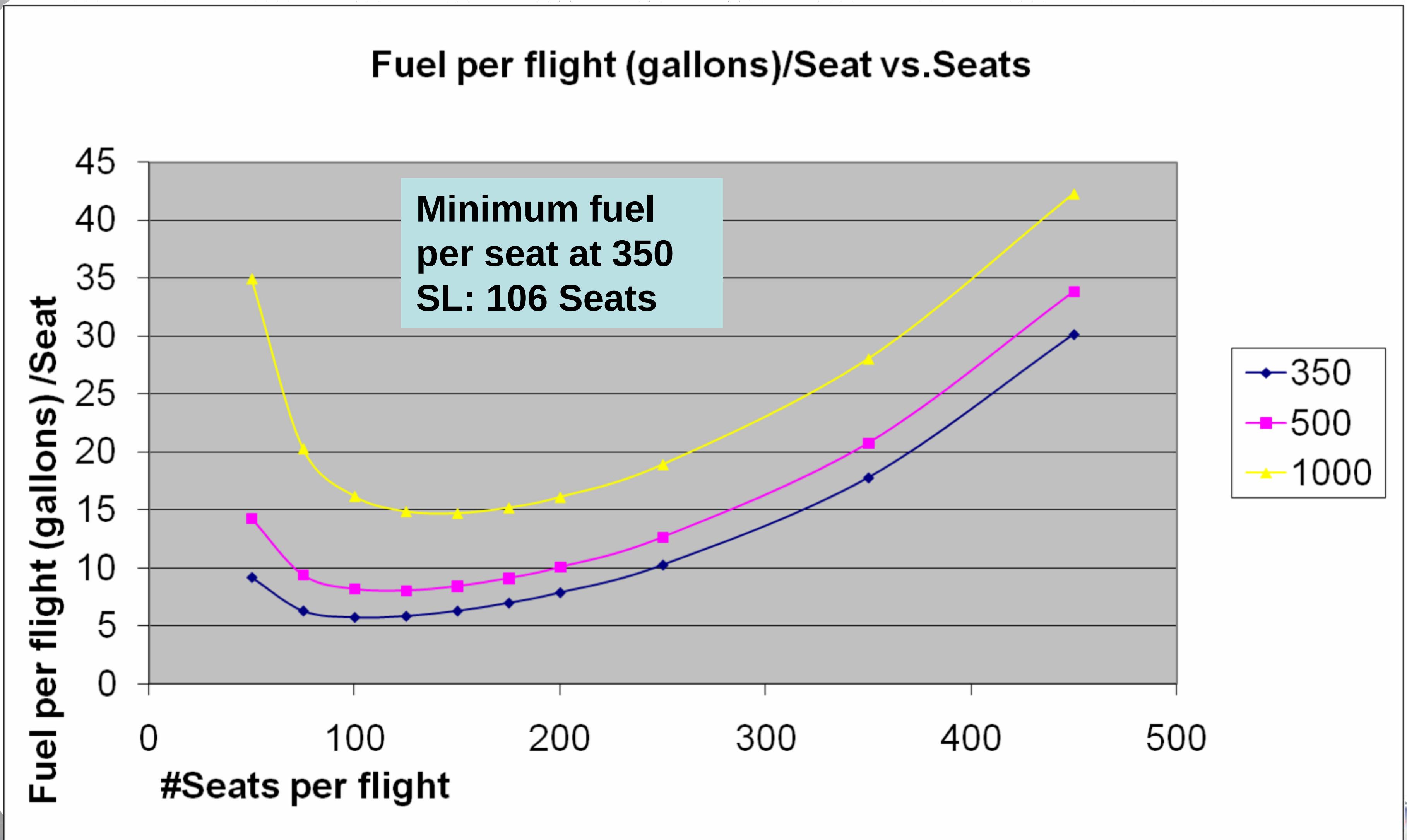
ln(fuel burn) =

$$7.3687 + .8938 * \ln\left(\frac{SL}{mean(SL)}\right) + .71742 * \ln\left(\frac{SE}{mean(SE)}\right)$$

$$+.7963 * \left(\ln\left(\frac{\mathrm{SE}}{\mathrm{mean(SE)}}\right)\right)^2 - .44182 * \ln\left(\frac{SL}{mean(SL)}\right) * \ln\left(\frac{SE}{mean(SE)}\right)$$

$$+ .016388 * Age + .013588 * Age * \ln\left(\frac{SE}{mean(SE)}\right)$$

Fuel Per Flight, Varied Stage Length and Seats per Flight



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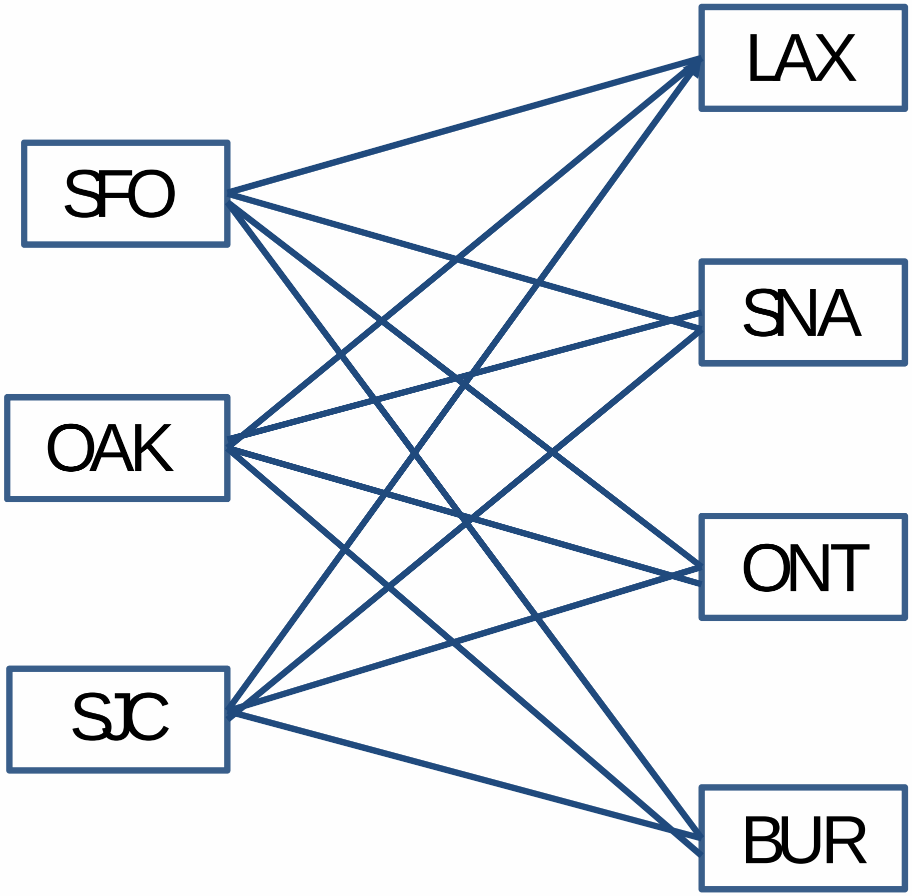
Study Network: The California Corridor

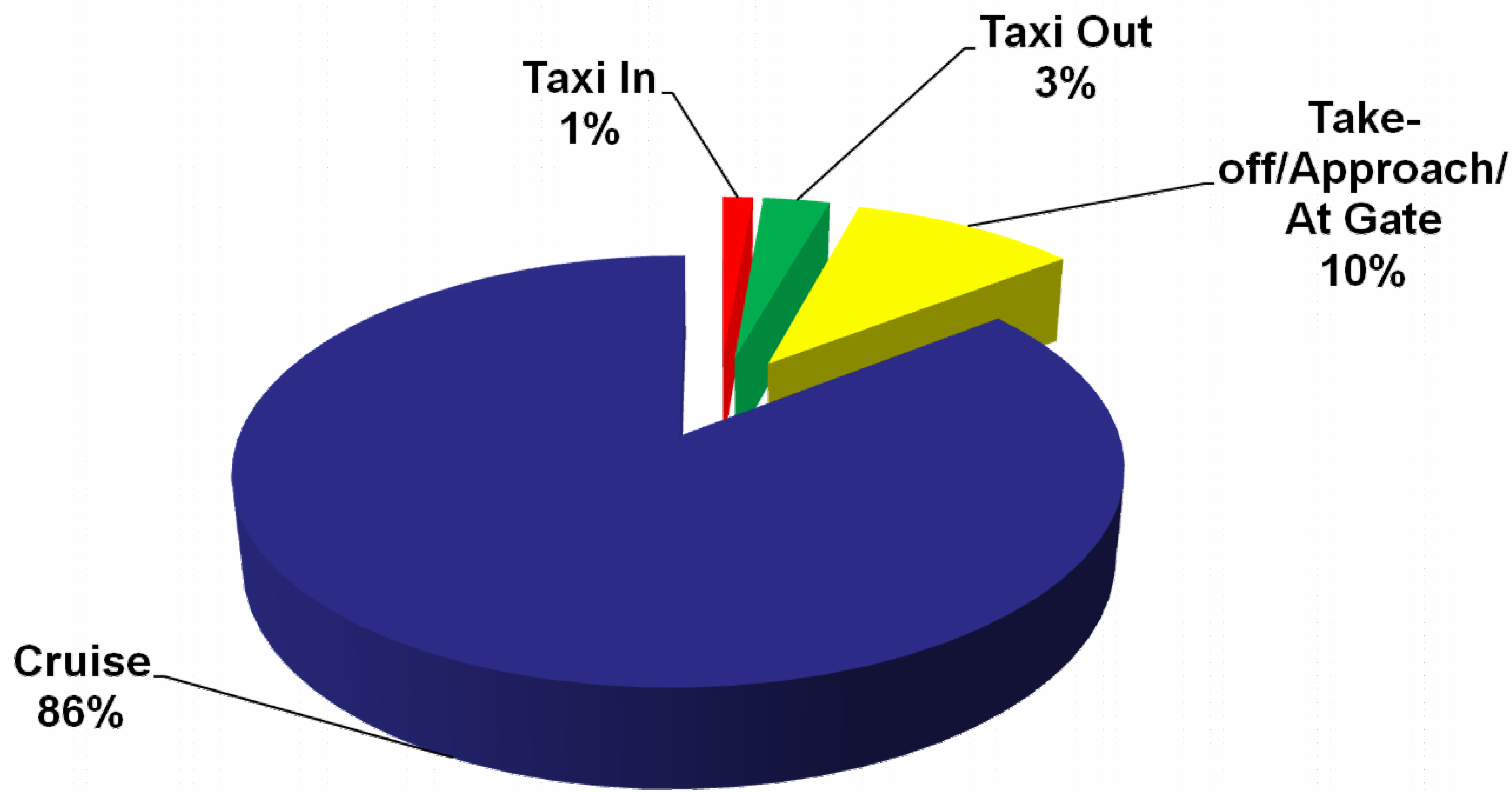


- **All flights between these airports on the study days**

Emissions Inventory Methodology

- Use BTS Data to obtain taxi times, stage lengths and tail number for all corridor flights
- Use World Fleet to match tail number with equipment and engine type
- Use ICAO database to obtain fuel flow for taxiing and LTO cycle
- Use fuel burn model and CO_2 conversion factors to predict total emissions from flights in this corridor
- Combine the above to break out total fuel

CO_2 Emissions: Average Flight Northern CA and Southern CA



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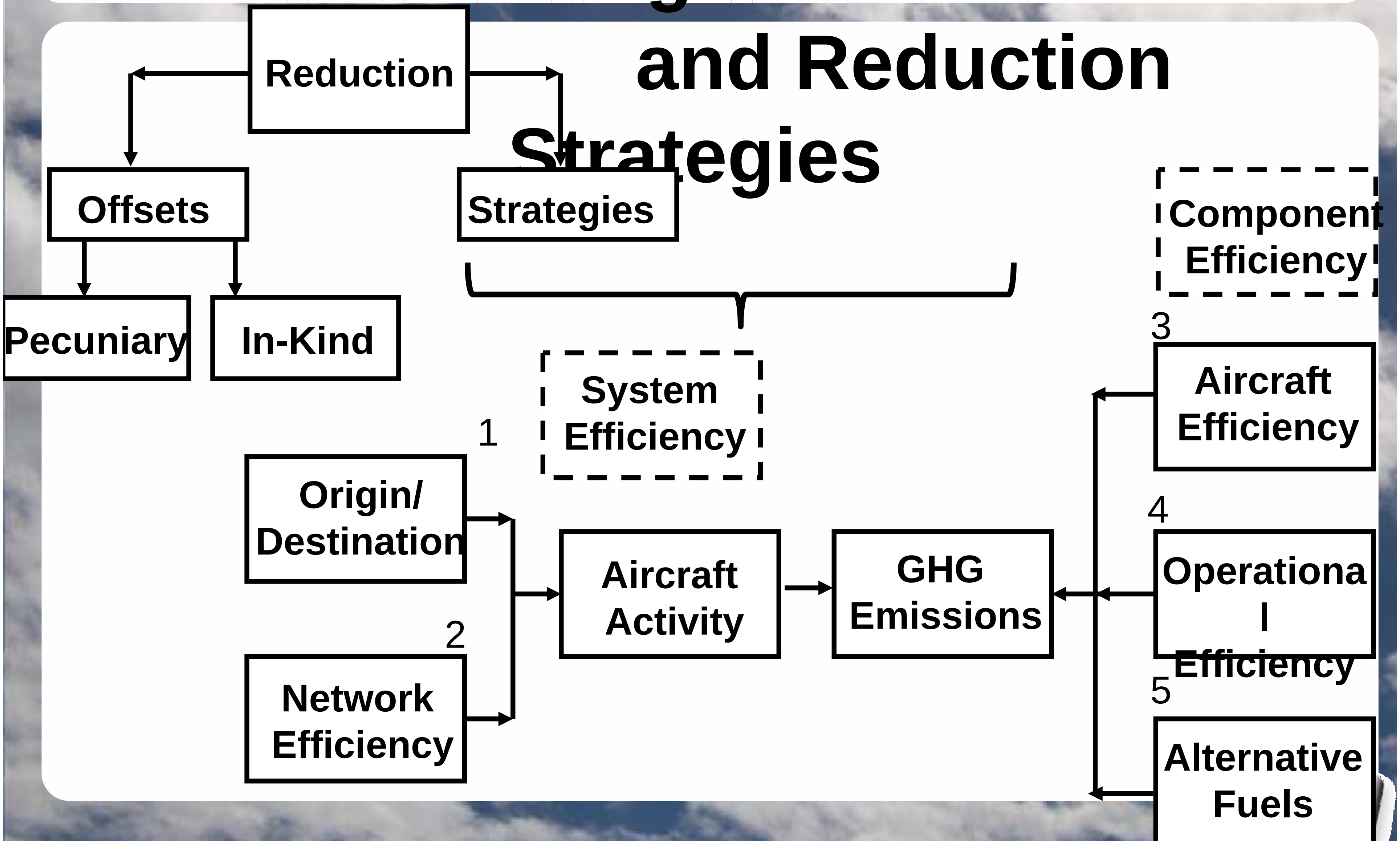
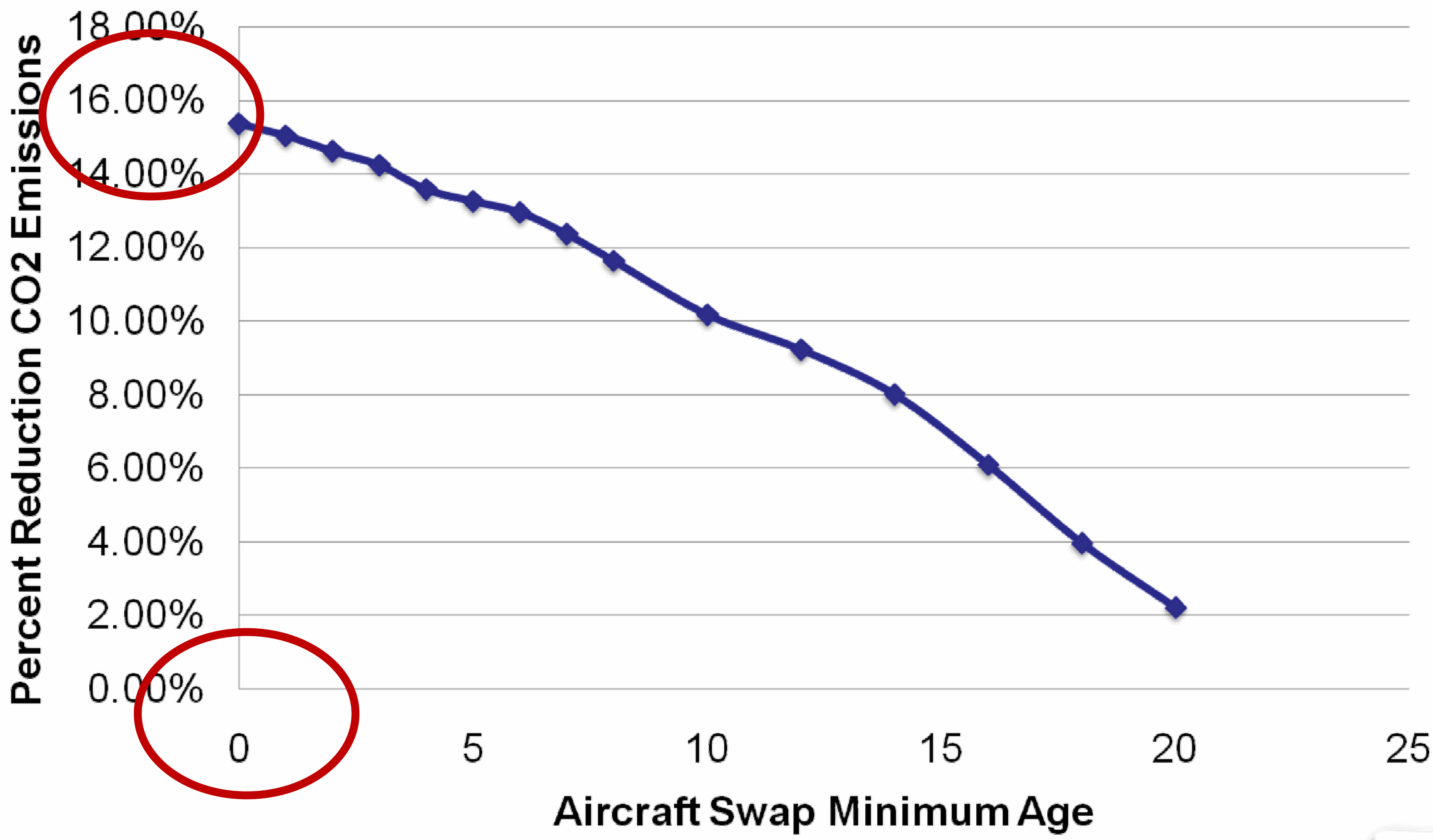
Taxonomy of CO_2 Emission Mitigation and Reduction Strategies



First Strategy: Aircraft Swap

- Replacement aircraft: brand-new 100 seat aircraft
- Perform a capacity-preserving aircraft swap
- Decision rule for swap based on a minimum age for replacement

Percent Reduction in CO_2 Emissions From Capacity Preserving 100 Seat Aircraft Swap



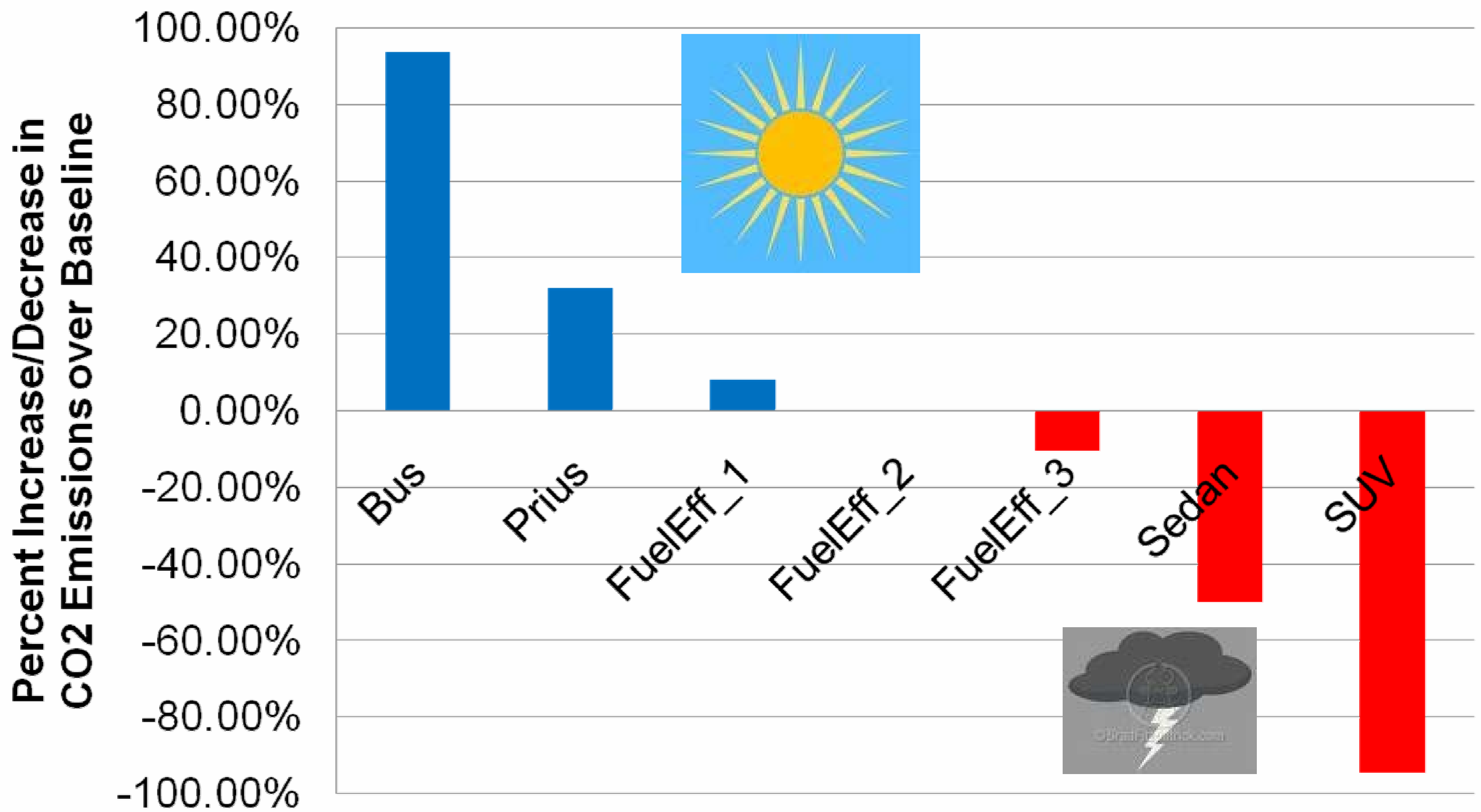
Aircraft Swap Strategy Cost

- Cost Accounting
  – New Boeing 717 Purchase Price 2004: $37.5 million
    - Daily cost of new B717: $5,991,055
      (20 year useful life, interest rate 15%)
    - 55% of flights per day on unique aircraft, average of 370*55% = 204 aircraft
  – Total cost: $3,348,425/day
- Daily Reduction: 332,203,570 lbs (166,100 tons)
- Cost/Ton: $3.35 million/166,100 tons= $20.16/ton

Second Strategy: Mode Shift to Surface

- **Investigate the possibility of reducing emissions through shifting modes**
- **Bus mode shift assumes capacity preservation and 40 seats/bus**
- **Vehicle mode shift assumes 75% load factor per flight and each passenger is shifted to a single vehicle**
    - **Prius**
    - **Sedan**
    - **SUV**

CO_2 Emissions Change (Savings) Compared with Baseline For Varying Surface Modes



Mode Shift Strategy Cost

- Cost Accounting
  - All travelers will drive a Prius to destination airport
    - 2008 price: $24,000, average 31,000 passengers per day
    - 31000 * $24,000 = $744 million in Prius purchases
    - Per day, with 10 year useful life and 15% rate: $406,147/day
  - Value of Time: 4 hr*31000*$50/hr = $6.2 million/day
  - Operating costs: $.40/mile*10.5 million miles/day
    = $4.2 million /day
  - Daily cost of strategy: $ 10.8 million/day
- Reduction: 1,905,917 lbs/day (9,523 tons)
- Cost of strategy: $10.8 million/9,523 tons =

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In-kind Mitigation: Investments in Clean Airport Access Modes

- **Augment baseline CO_2 emission inventory to include airport access mode CO_2 emissions**
- **Replace with Electric Vehicle bus ($CO_2 \rightarrow 0$)**
- **Determine CO_2 emission reduction and cost**

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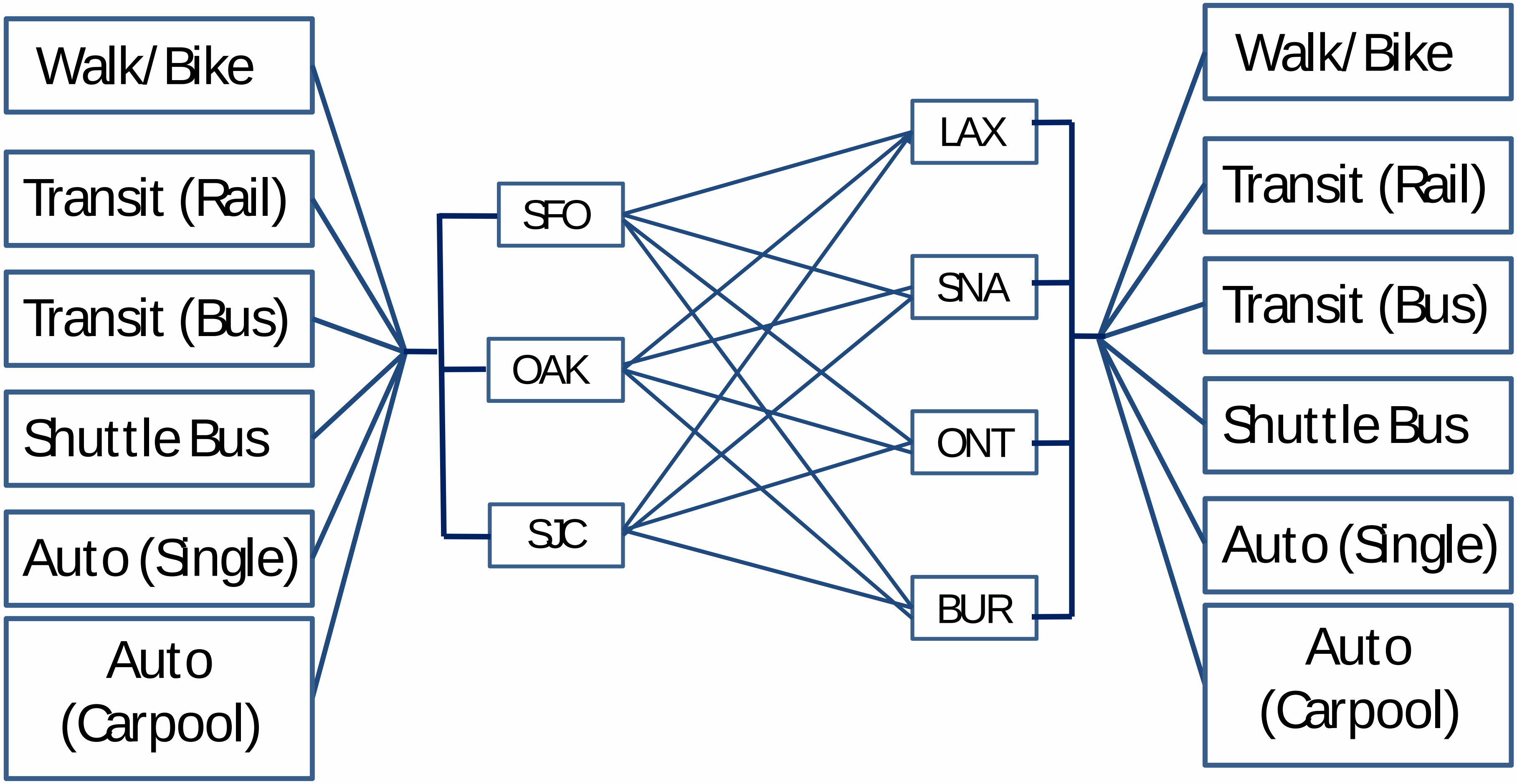
Aviation Access Mode Network



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Quantifying Access Mode CO_2 Emissions

Northern California

MTC 2001 Airline Passenger Survey

Origin Airport

Destination Airport

Access Mode

Trip Origin Zip Code

Mode Share
Per Zip Code
Per Origin Airport
generalizes to sample days

Mode	GHG Emissions Operational (g GGE/ PMT)
Sedan	230
SUV	280
Urban Bus	330
BART	230

CO_2 Emissions for all trips
Per Mode
Per Zip Code
Per Origin Airport

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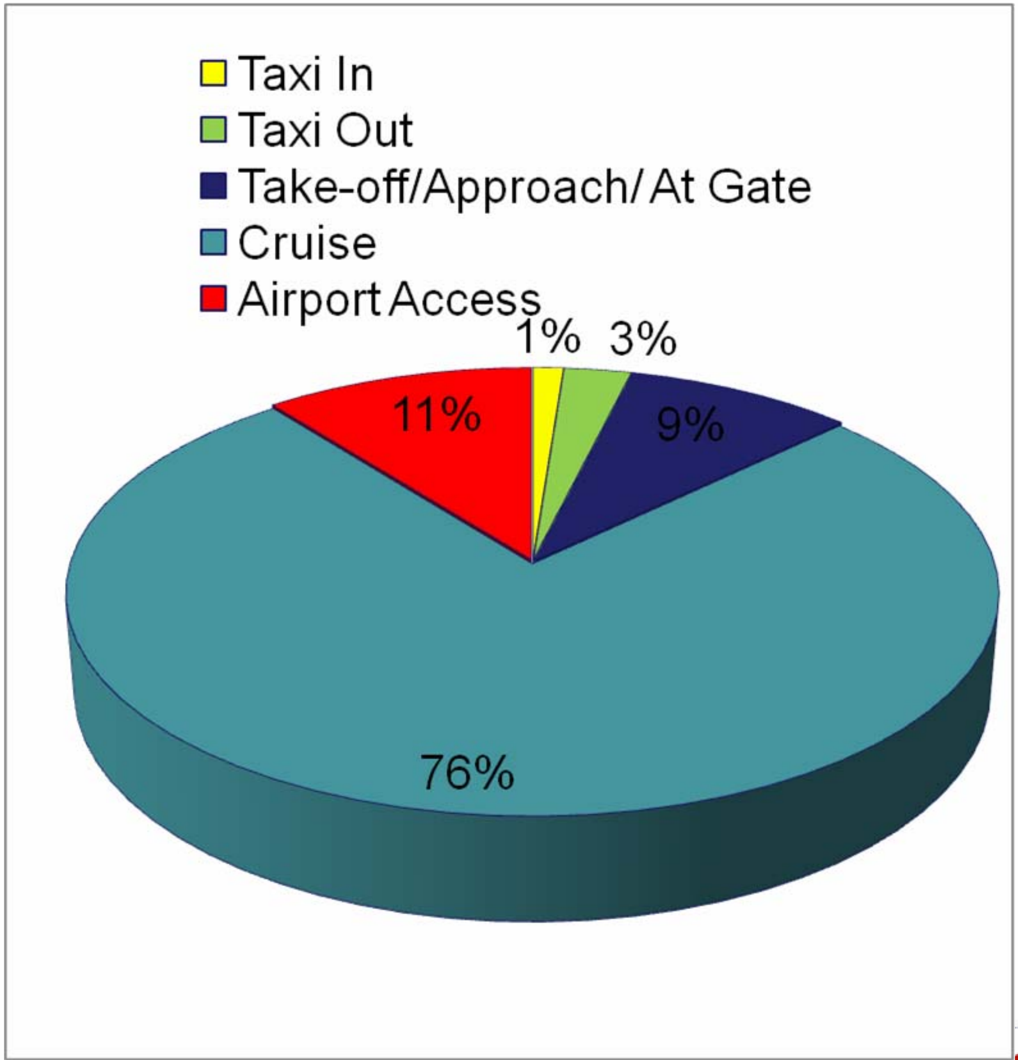
Multi-Modal CO_2 Emissions Distribution

If we broaden our view of aviation-related emissions to include access modes, aircraft operators could save 11% over baseline CO2 Emissions from going to electric vehicles



Access Mode Strategy Cost

- Cost Accounting
  - Buy 50 electric buses at $70,000 per bus
    - Cost per day = $559,165

      Useful life: 20 years, interest rate: 15%
  - Contract Bus Operators & Maintenance

    20,000 per year/365 * 50 buses * 2 drivers per bus= $5,480
  - Time Cost = 20*2 min * 31000 pax * $50/hr =

    $1.03 million/day
  - Daily cost of strategy: $1,597,978/day
- Reduction: 702,148 lbs/day (351 tons)
- Cost/Ton: $1.6 million / 351 tons = $4,553/ton

Conclusions & Final Thoughts

- **Certain reduction strategies are competitive with mitigation costs at projected CO_2 emissions prices**
- **Lifecycle costs**
  - **Operations are not the whole story**
  - **Over the life of an aircraft operational CO_2 emissions ~70%**
- **System-wide impacts**
  - **Some reduction strategies may require increased airport and airspace capacities (NextGen)**
  - **Other reduction strategies may require increased road capacity**

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