NREL
NATIONAL RENEWABLE ENERGY LABORATORY

URBAN NEXUS INITIATIVE | *Science Toward Solutions*

Aligning Incentives and Public-Private Actors to Realize Co-benefits for Smart Urban Mobility

BECC | October 21, 2016

Joshua B. Sperling, Ph.D., Urban Futures & the Energy-X Nexus @ the New Concepts Incubator | Joint Institute for Strategic Energy Analysis | Transportation Center at the National Renewable Energy Laboratory

U.S. DEPARTMENT OF ENERGY

SMARTMOBILITY

Systems and Modeling for Accelerated Research in Transportation

$12.5M Multi-Lab Effort

Bringing Science to the Conversation

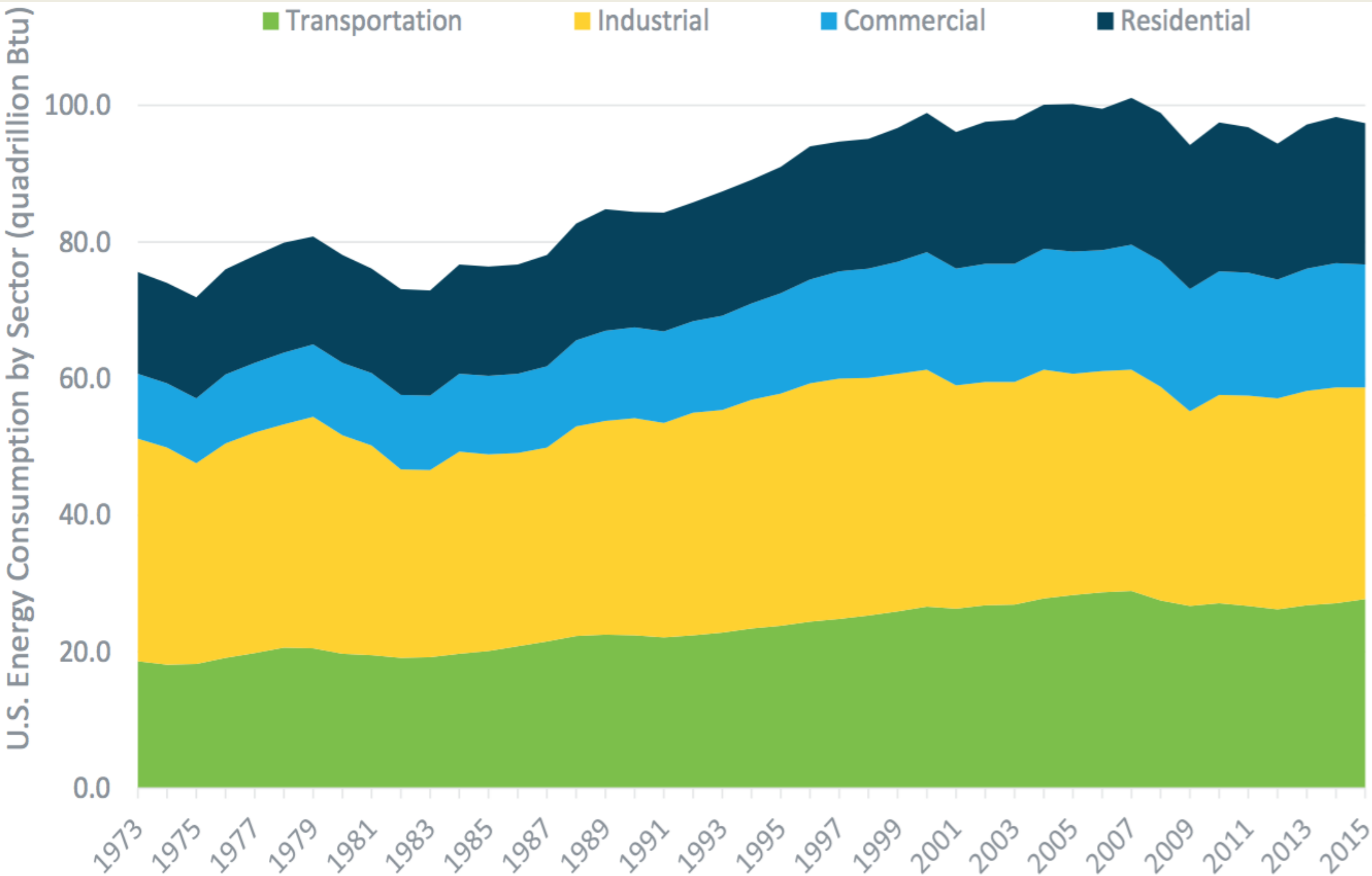
- Multi-modal transport of people and goods
- Market adoption through informed infrastructure investments
- Understanding consumer mobility decisions
- City-scale urban mobility models for planning
- Connectivity & automation to enable safety, energy, and mobility

Talk Outline & Key Messages

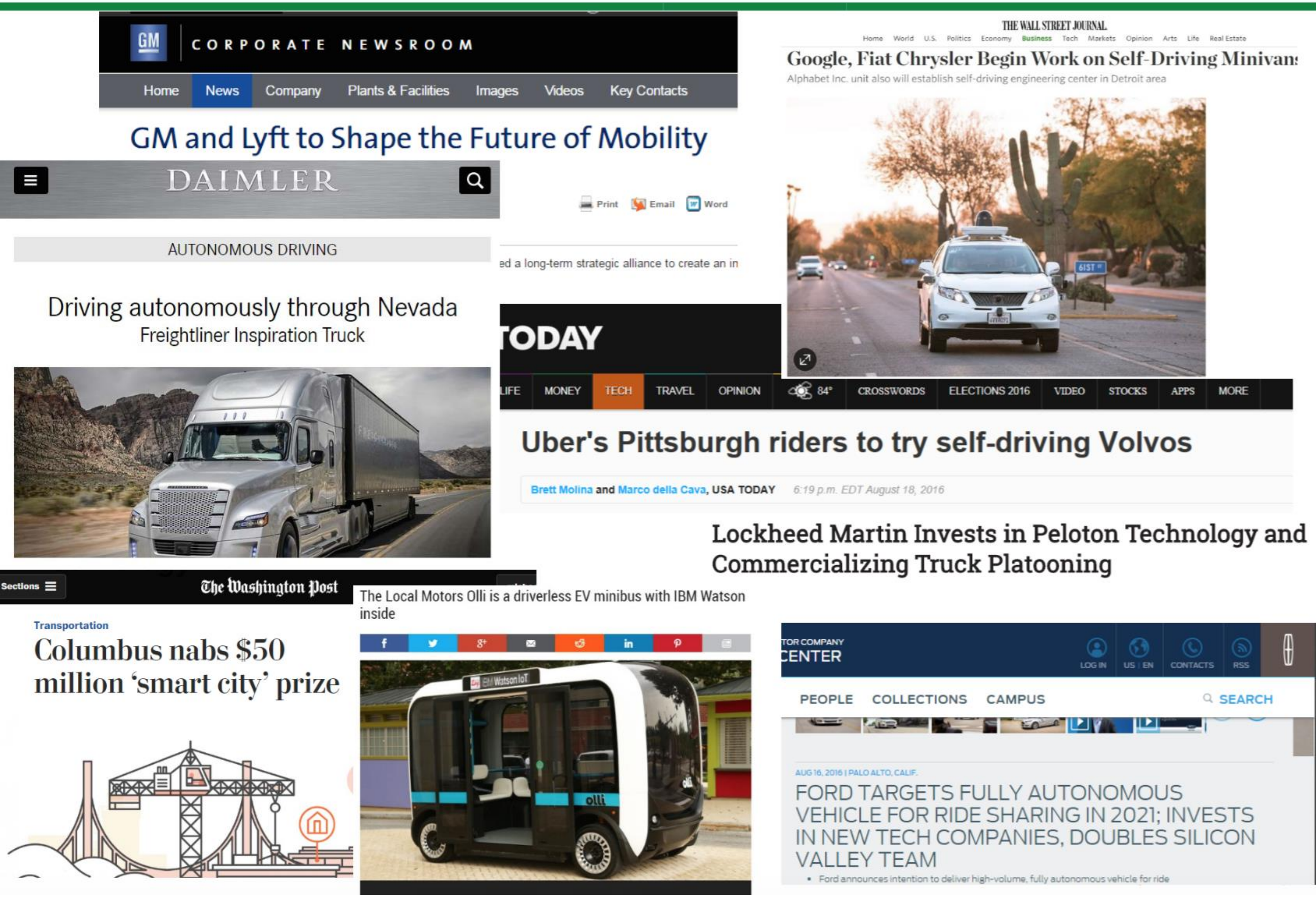
- A Need for Empathy and Urban Nexus Science /Energy Efficiency Innovation across cities of US & Globally
- DOE SMART Project: Addressing the Nexus of Energy, Urban Sustainability, and Decision/Behavioral Sciences with Interdisciplinary Integration and Co-Design
- Preliminary Urban Science and 'Humans-in-the-Loop' Study (in Denver) to demonstrate/further catalyze integrated urban energy and mobility systems/services that people value w/ co-benefits for energy-efficient-healthy-resilient cities

Transportation is over 30% of US Energy Consumption

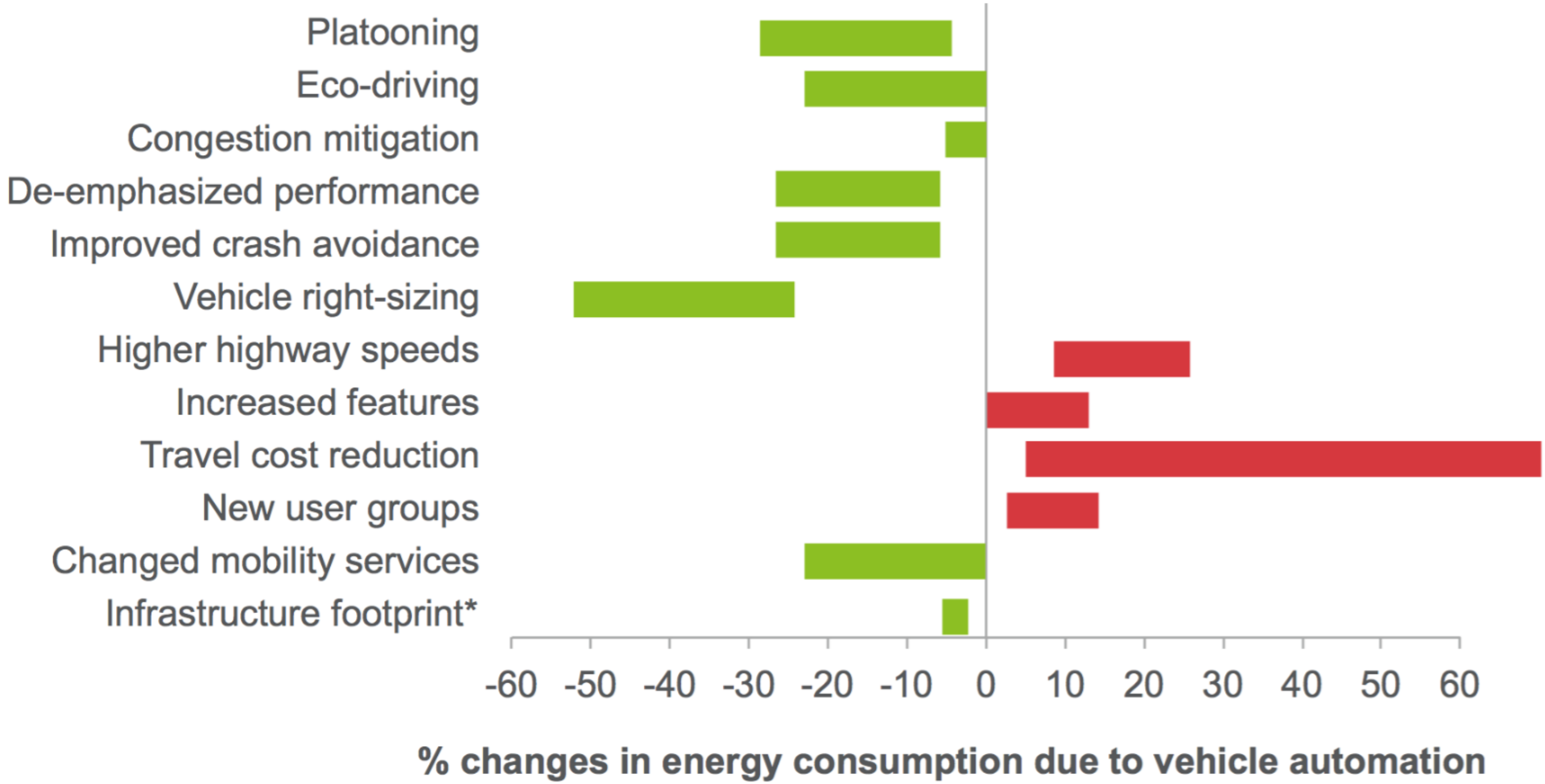
Nichols & Kochelman, 2015: Transport and Land Use/Urban Form Critical to Global Urban Energy Demands- Increases in resident & employment density offer substantial per capita energy savings: ~18,22, and 24% for Phoenix, Austin and Seattle settings relative to an Orlando-based design (when multiple factors controlled).



Fundamental Disruption is Occurring in Transportation



Significant /Uncertain Implications for Energy / Behaviors: Connected and Automated Vehicle Energy Impact Analysis



Does increased Connectivity, Automation, and Mobility lead to increased or reduced transportation energy use and GHG emissions?

Brown, A.; Gonder, J.: Repac, B. (2014). "An Analysis of Possible Energy Impacts of Automated Vehicles." Chapter 5, Societal and Environmental Impacts. Meyer, G., ed*. Lecture Notes in Mobility: Road Vehicle Automation.* Berlin: Springer.

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Get Out of Your Box: Co-Production of Urban Nexus Science & Innovation for the 21st Century

Josh Sperling | September 7, 2016

Co-Producing Knowledge: URBAN FUTURES & the ENERGY-X NEXUS (X= Mobility-Land- Buildings-Air-GHG)

www.nrel.gov and www.ral.ucar.edu/csap/themes/urbanfutures

Acknowledgements

- DOE
- National Renewable Energy Laboratory
- University of Colorado-Denver/Boulder
- China and India Colleagues
- Fulbright, NSF, & many others..

> *"The essence of intercultural education is the **acquisition of empathy**– the ability to see the world as others see it, and to allow for the possibility that others may see something we have failed to see, or may see it more accurately."*
>
> *– William J. Fulbright*

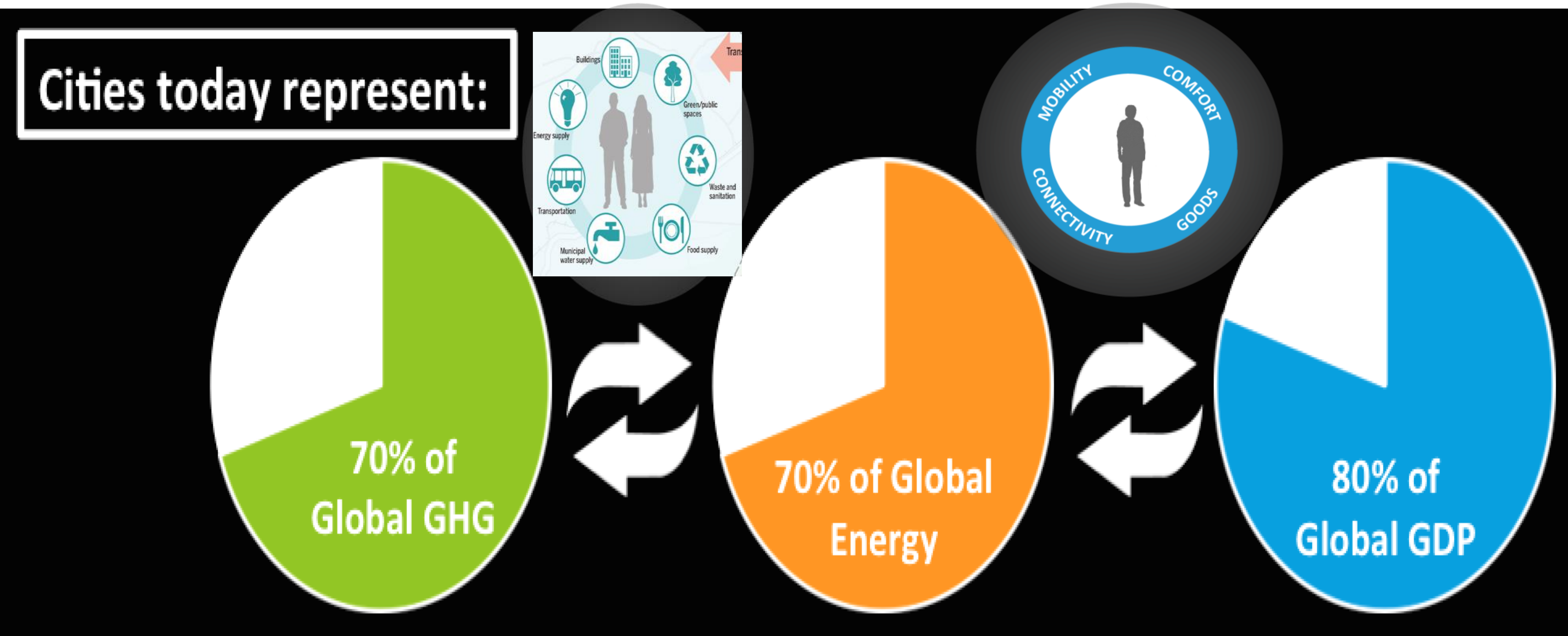
A Challenge :

Info/Incentives/Social Norms for New Sustainable Behaviors?

An Opportunity?

Global Challenge: Low-Carbon, Sustainable Cities/Urbanization for People to Live and Thrive

- "If current trends in urban expansion continue, urban energy use will increase more than threefold, from 240 in 2005 to 730 EJ in 2050"



21st Century: Engineering-Planning-Policy-Behavior Sciences for Urbanization

New urbanization projections (prepared for Rethinking Cities, World Bank, 2014):

- **CHALLENGE**: 10B urban people? 87% urban planet? 21st century = 3x more urban residents in 'less developed' world? What will be the infrastructures/institutions of a healthy urban planet?
- **OPPORTUNITY:** "Urban population will be split unevenly, with just 1.2B living in cities of what we now think of as developed countries and 8.6B in cities of the developing world."

The Developing World's Urban Population Could Triple by 2210

	Urban residents			Population
Year	Less developed	More developed	World	World
1910	4% 0.04	15% 0.14	19% 0.18	0.93
2010	38% 2.6	14% 0.96	52% 3.6	6.9
2110	71% 7.8	11% 1.2	82% 9.0	11.0
2210	76% 8.6	10% 1.2	87% 9.8	11.3

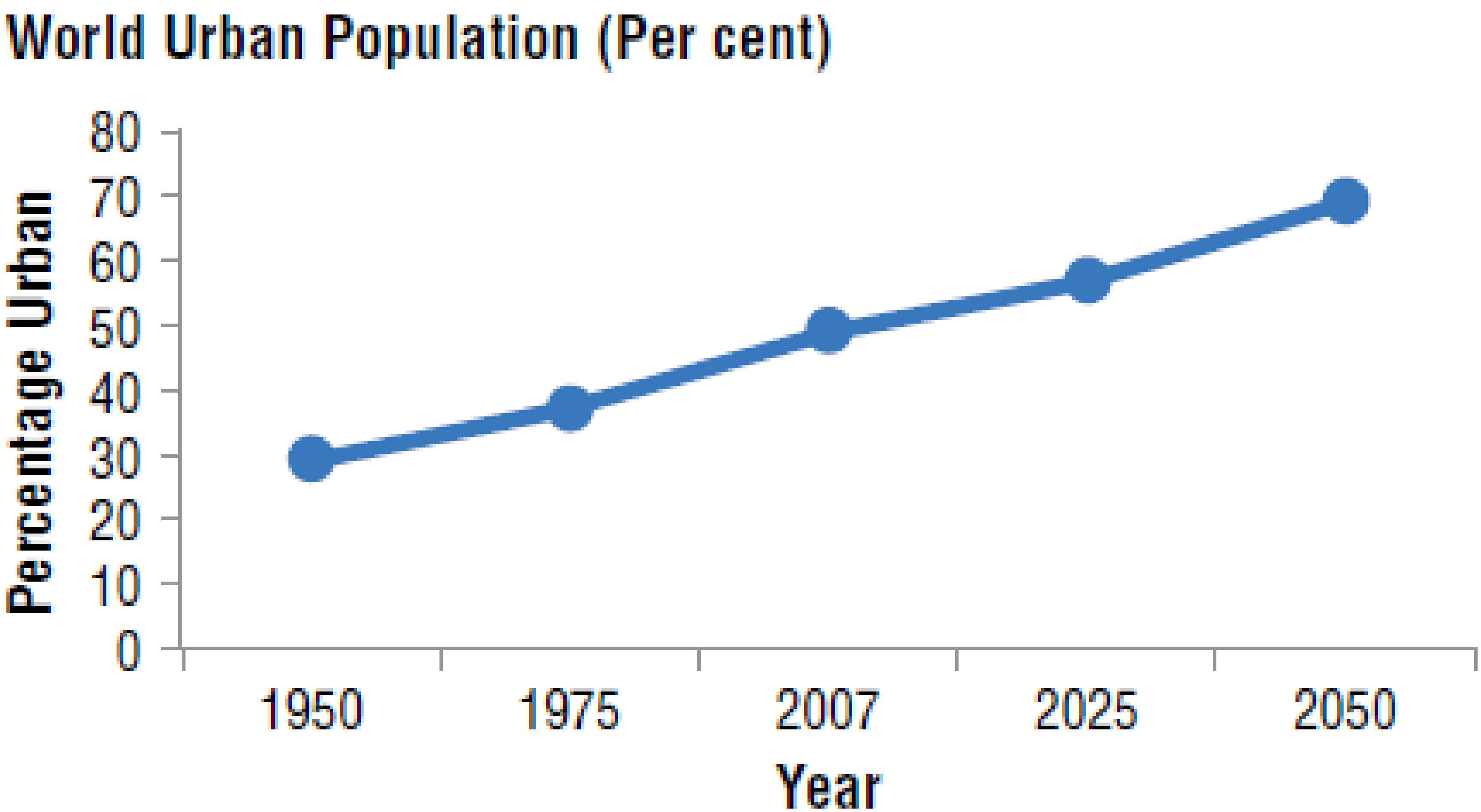
Fuller and Romer, 2014. Urbanization as Opportunity. (Calculations based on UNDESA, 2012)

IN THE NEXT 3 DECADES, ALMOST 2 BILLION ADDITIONAL PEOPLE WILL POPULATE THE EARTH. THIS GROWTH WILL CREATE DEMANDS ON AN UNPRECEDENTED SCALE FOR:

ENERGY PRODUCTION	FOOD SUPPLY	WATER PRESERVATION	WASTE DISPOSAL
ENVIRONMENTAL CLEANUP	SUITABLE LIVING CONDITIONS	HEALTH CARE	INFRASTRUCTURE
MATERIALS HANDLING	LAND STABILIZATION	EARTH MOVING	TRANSPORTATION DEMAND

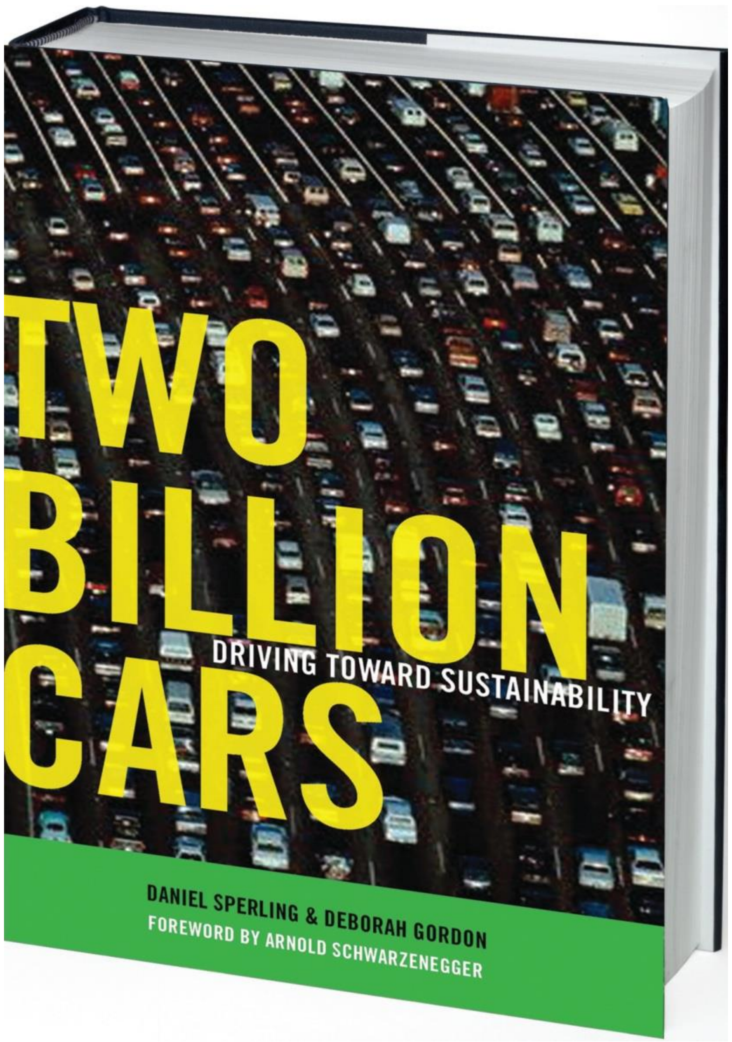
Amadei, 2009

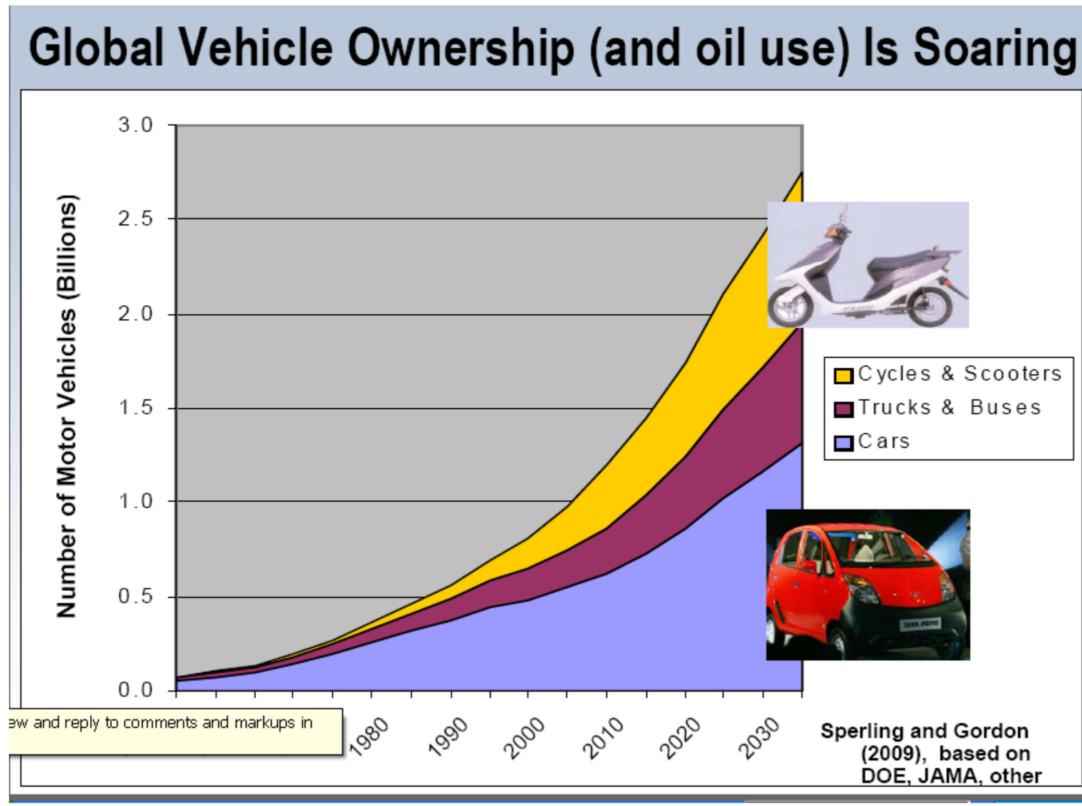
- Approximately 75 % of the infrastructure required that will be in place in 2050 does not even exist today (ICLEI 2015)
- Delhi: a doubling of power requirements 2009-2014 (CEA, 2011)

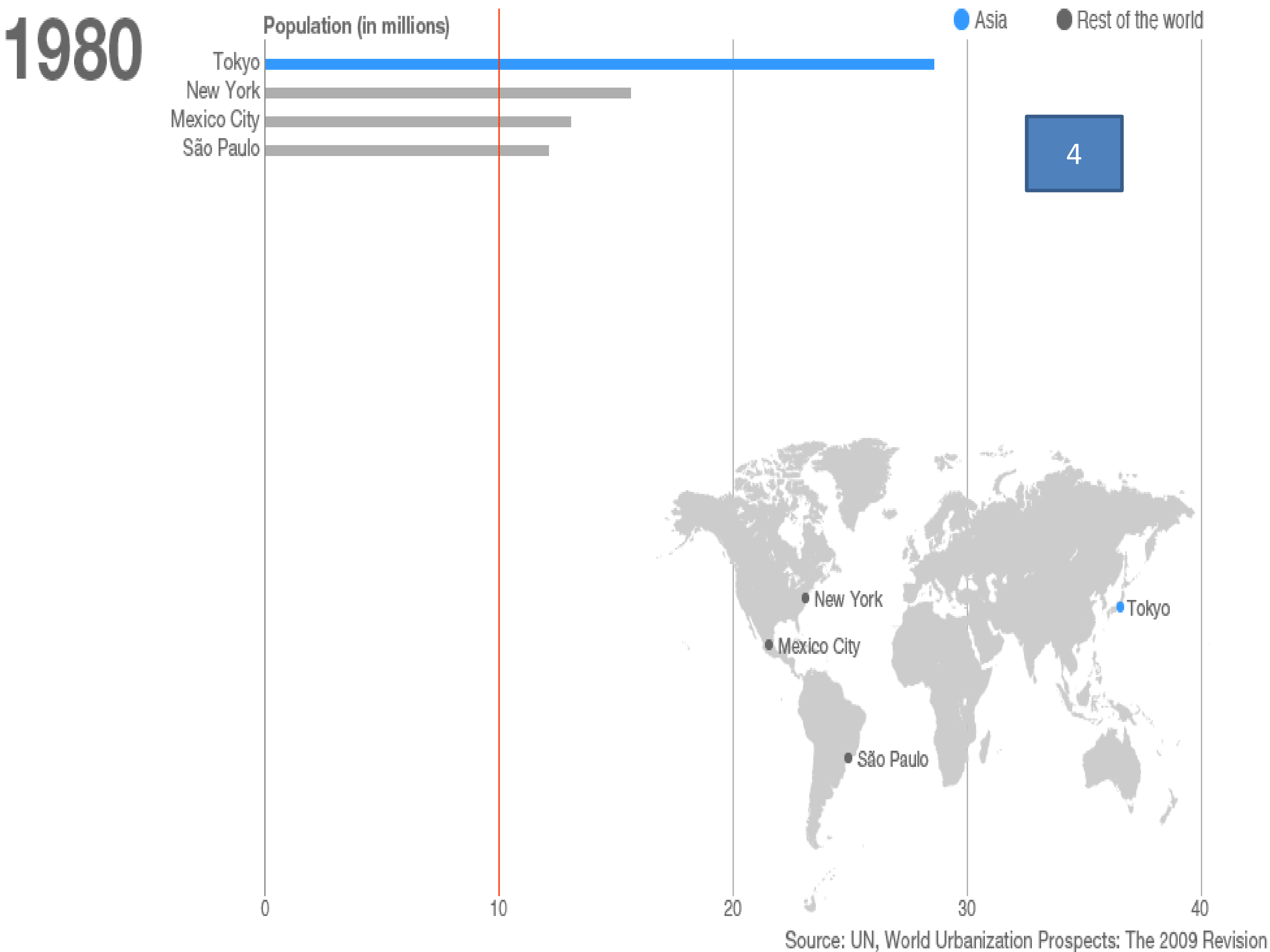


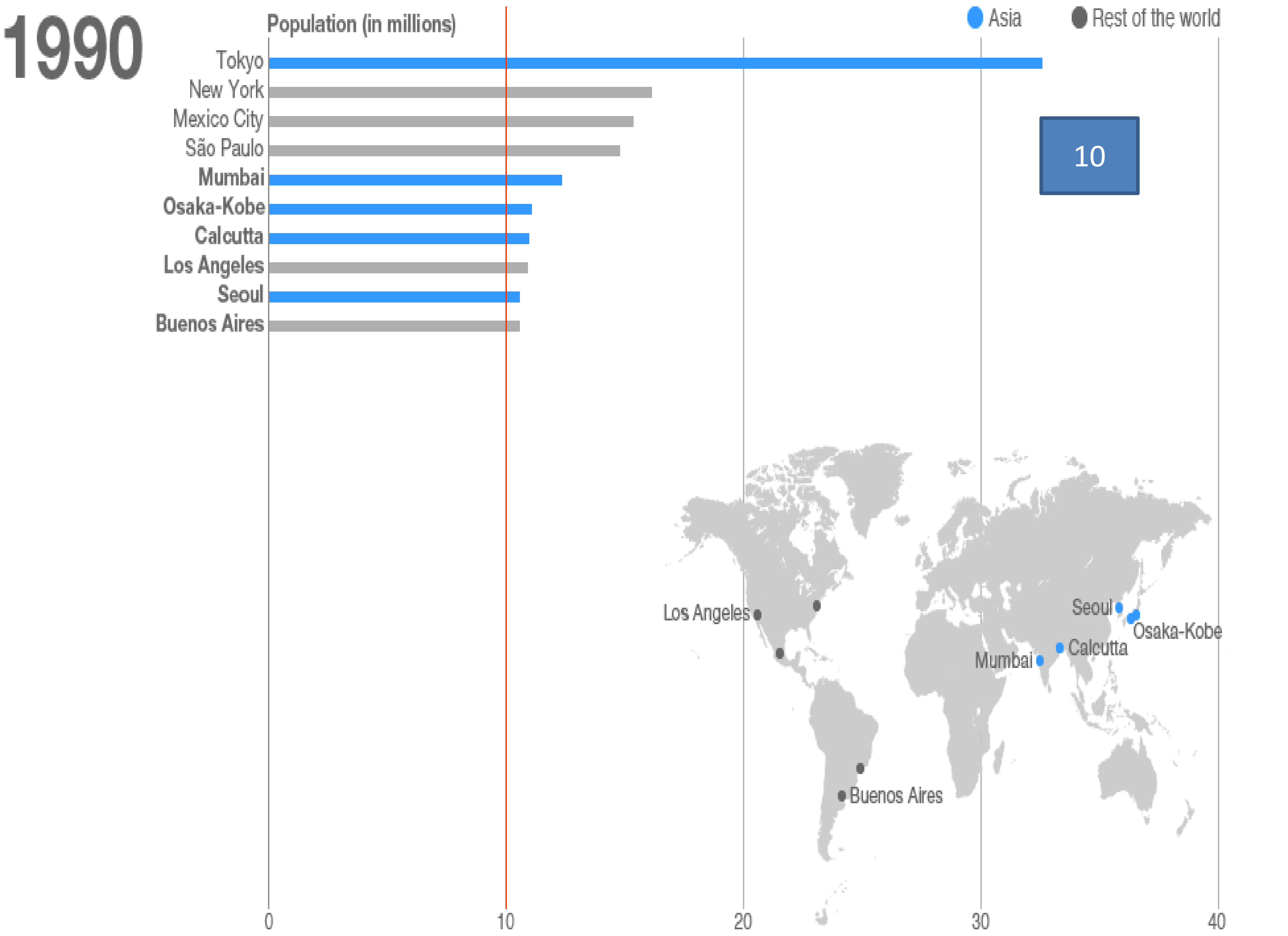
Data source: United Nations Population Division, (2008)

Impact of Transport…

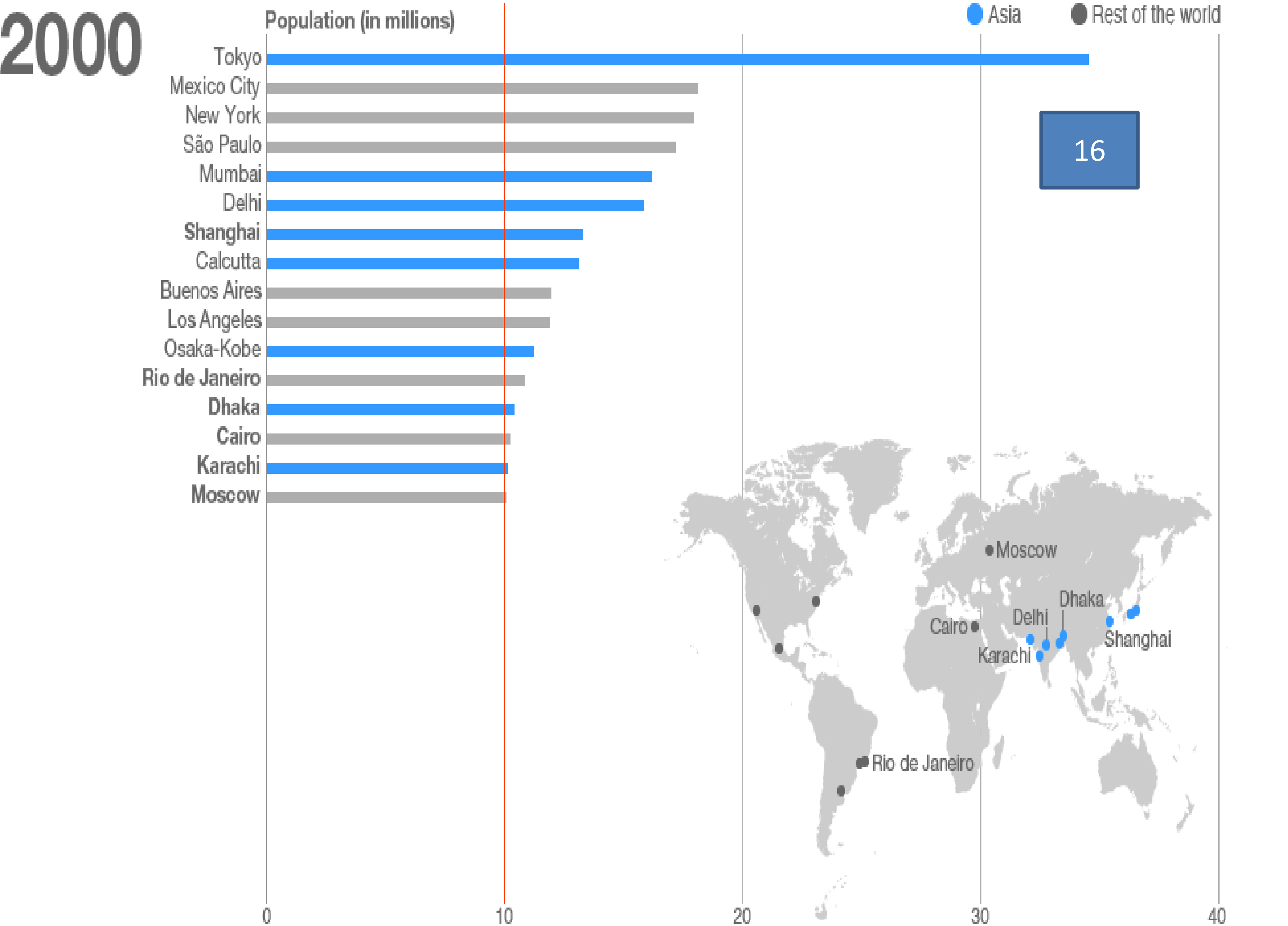




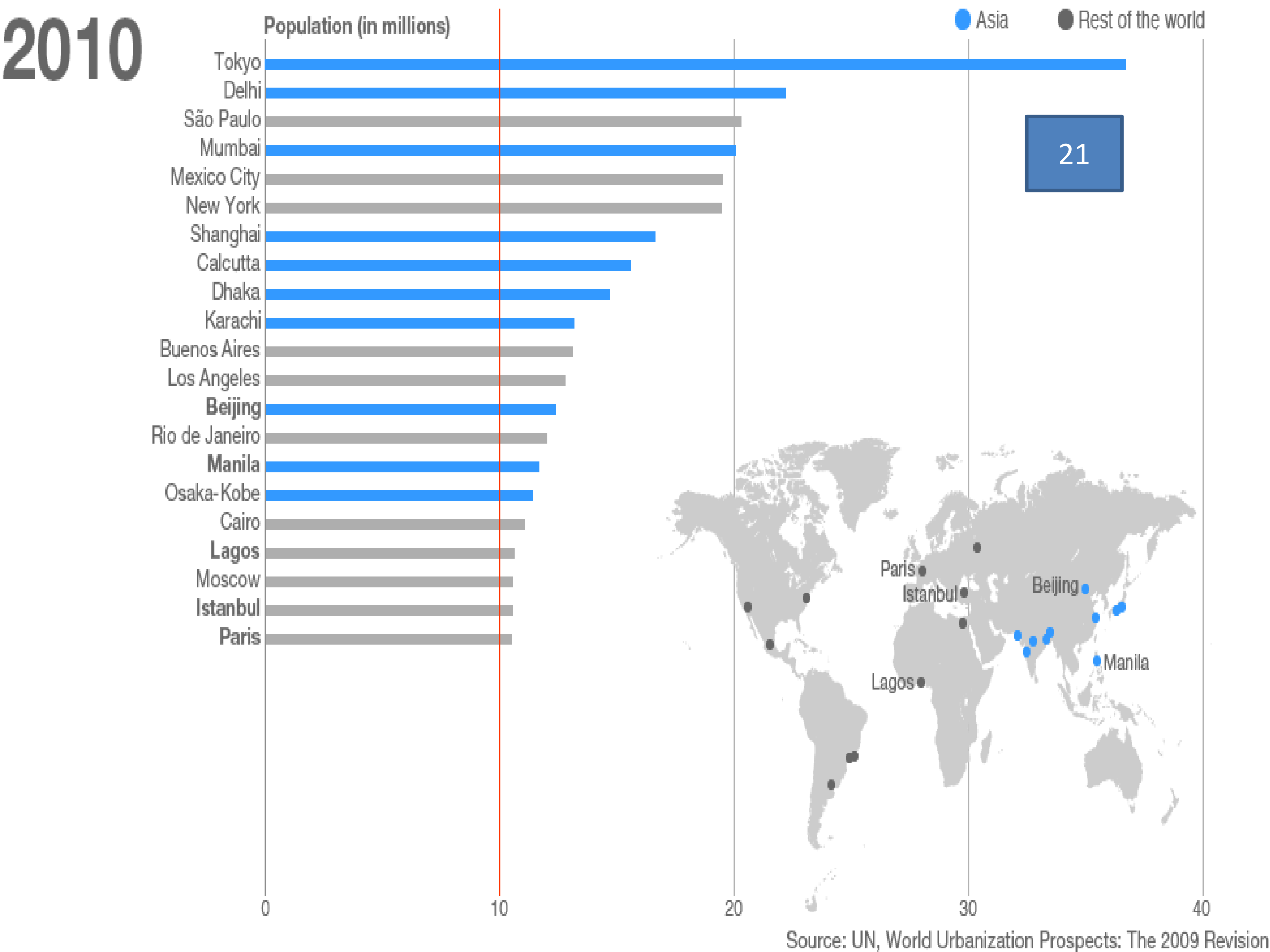

1980
Population (in millions)
Asia
Rest of the world
Tokyo
New York
Mexico City
São Paulo
4
New York
Tokyo
Mexico City
São Paulo
0
10
20
30
40
Source: UN, World Urbanization Prospects: The 2009 Revision



Source: UN, World Urbanization Prospects: The 2009 Revision

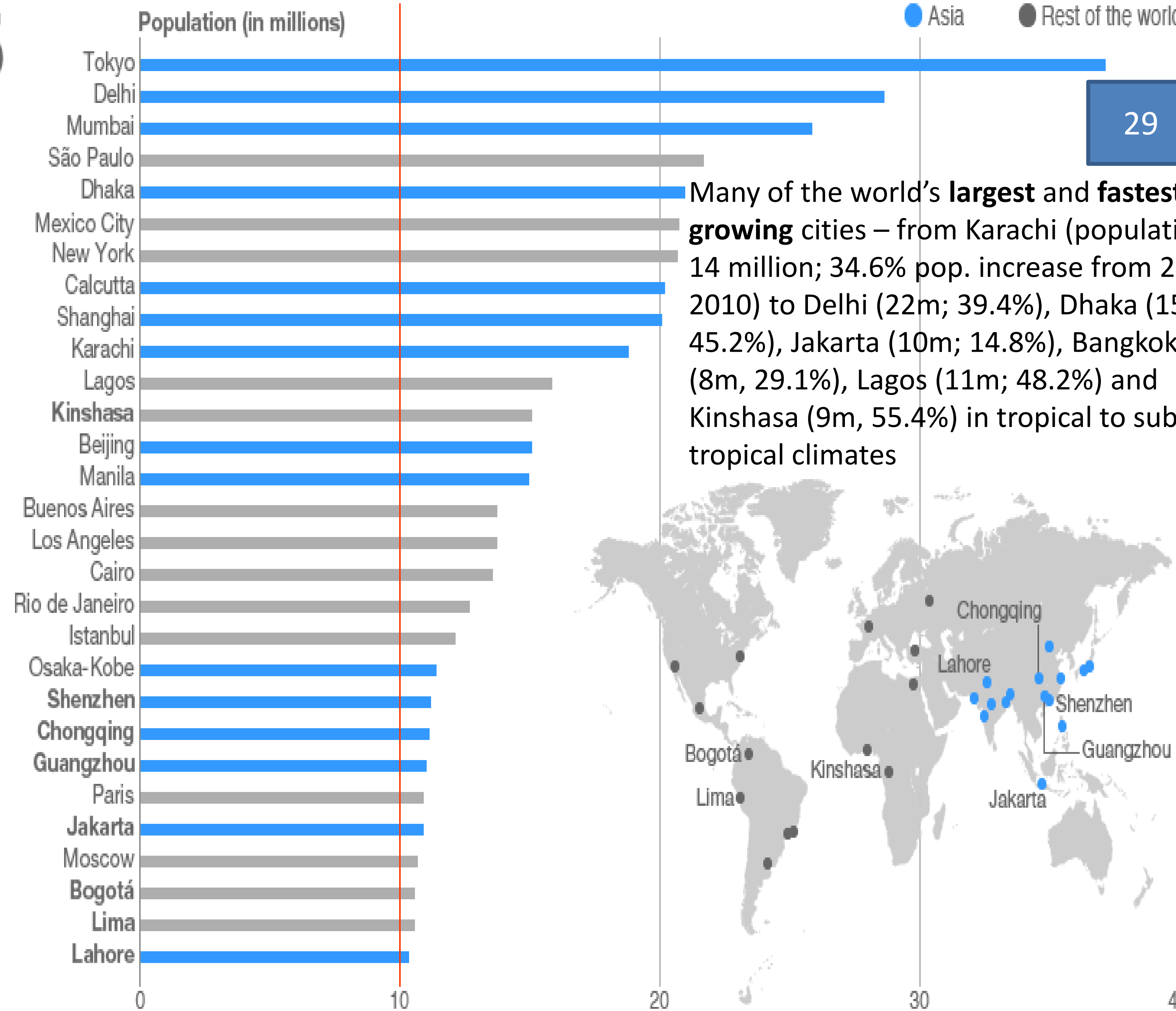


Source: UN, World Urbanization Prospects: The 2009 Revision



2010
Population (in millions)
Asia
Rest of the world
Tokyo
Delhi
São Paulo
Mumbai
Mexico City
New York
Shanghai
Calcutta
Dhaka
Karachi
Buenos Aires
Los Angeles
Beijing
Rio de Janeiro
Manila
Osaka-Kobe
Cairo
Lagos
Moscow
Istanbul
Paris
21
Paris
Istanbul
Beijing
Manila
Lagos
0
10
20
30
40
Source: UN, World Urbanization Prospects: The 2009 Revision

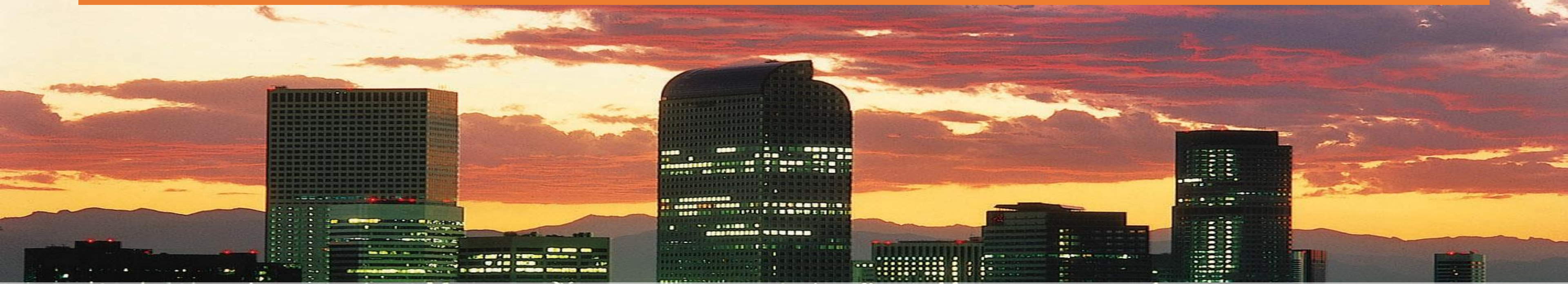
2025



Many of the world's **largest** and **fastest-growing** cities – from Karachi (population 14 million; 34.6% pop. increase from 2000-2010) to Delhi (22m; 39.4%), Dhaka (15m, 45.2%), Jakarta (10m; 14.8%), Bangkok (8m, 29.1%), Lagos (11m; 48.2%) and Kinshasa (9m, 55.4%) in tropical to sub-tropical climates

Source: UN, World Urbanization Prospects: The 2009 Revision

Interdisciplinary and international experiences



- IGERT-Sustainable Urban Infrastructure (Engineering-Planning-Policy-Health&Behavioral Sciences)
- Fulbright-Nehru Program, UCD, CU-Boulder, LBNL, UNSW, RMIT, Columbia, NYU, MIT, TERI U
- ARUP, BRAC, EWB-Int’l, UN WWO / WEF / Youth Assembly / UN-Habitat, UNDP Equator Prize
- Studies, work, travel, field research & volunteer activity in various countries abroad, primarily in Americas / Asia: extended visits to Chile-DR-Bangladesh-India-Nepal-AUS-China

Current/Future: NCAR RAL CSAP UF, UCD, cross-national research in cities of Asia & the Americas

NSF PIRE: Developing Low-Carbon, Healthy and Resilient Cities in the US, China, India

- **Integration Across Engineering, Envmt'l Sciences, Social Sciences, & Public Health**: Year 1: India; Year 2: China; Yr 3: US
- Focus: reducing GHG emissions and addressing broader sustainability goals - economic development, water scarcity, environmental pollution, climate change and public health.
- Four themes across a typology of city-types: megacities (10% of WUP), smaller mature and rapidly industrializing cities (<1M; >60% of WUP)

Transboundary GHG / Environmental Footprints (Energy- Buildings-Transport-Food-Water-Waste-Materials-PublicSpace)	**Infrastructures, Environment, and Health (Outcomes / Inequities)**
Modeling City Strategies (Transportation, FEW, Waste & Industrial Symbiosis)	**Social Actors and Multi-Level Governance (Priorities / Capacities)**

URBAN X

Information

1. **Community Engagement** — *Connect*
2. **Data Research** — *Integrate*
3. **Thought Leadership** — *Inspire*
4. **Co-Design Change** — *Implement*
5. **Analytical Insights** — *Validate*

THE WAYS WE CAN ENGAGE

VISION

A convergence of humans-in-the-loop and urban sustainability approaches toward integrating critical knowledge, data, tools, and design best practices that can be leveraged and shared across sectors and domains to support energy systems and services that reduce environmental impacts, improve quality of life and create sustainable urban systems.

MISSION

Towards energy systems, infrastructure services, for sustainable, healthy and resilient cities

URBAN X

OUR APPROACH *is*

Interdisciplinary • Human-Centered • Systems Oriented

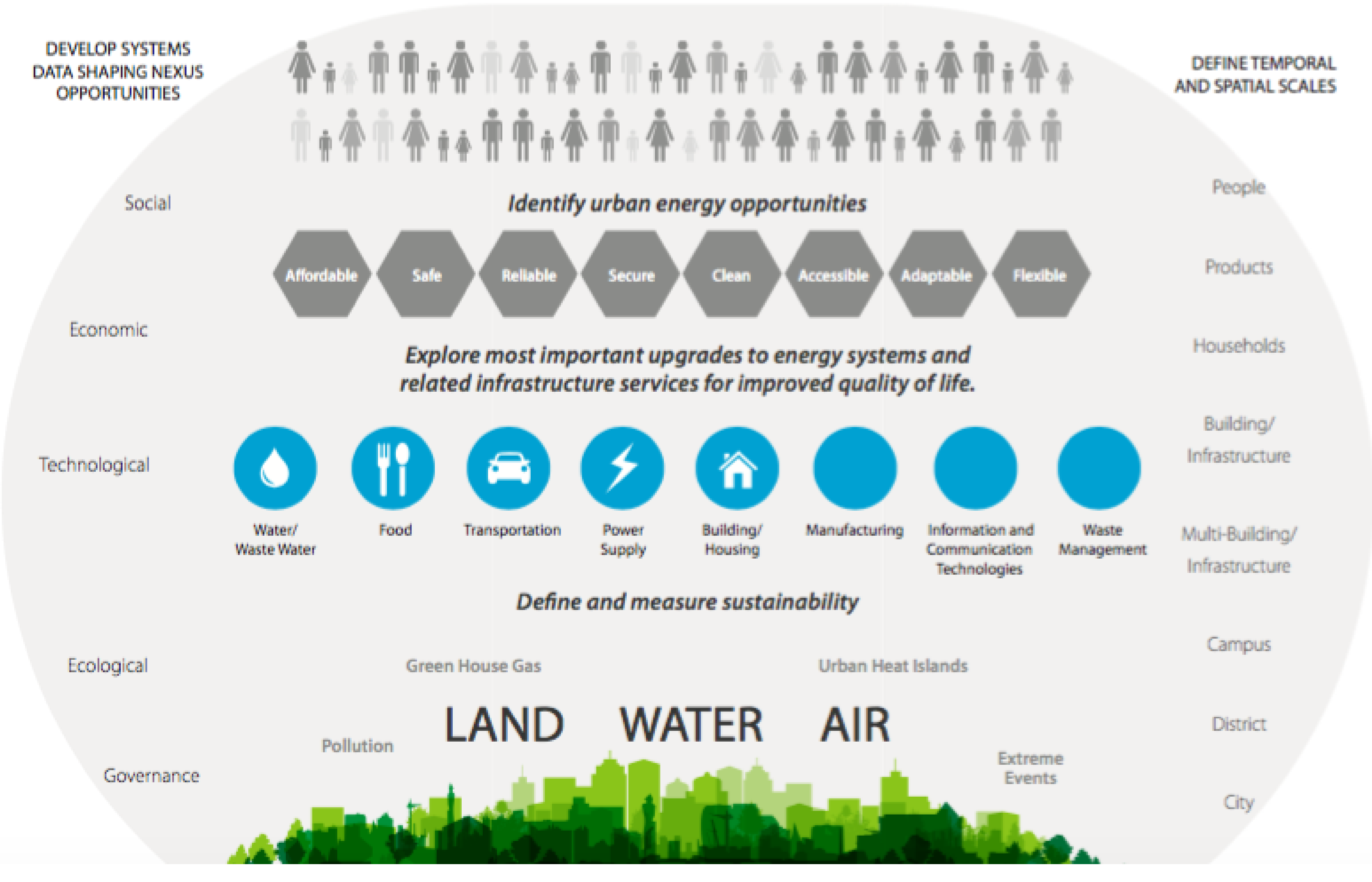
Research …Objective and credible data, tools, and analysis for integrated insights/knowledge

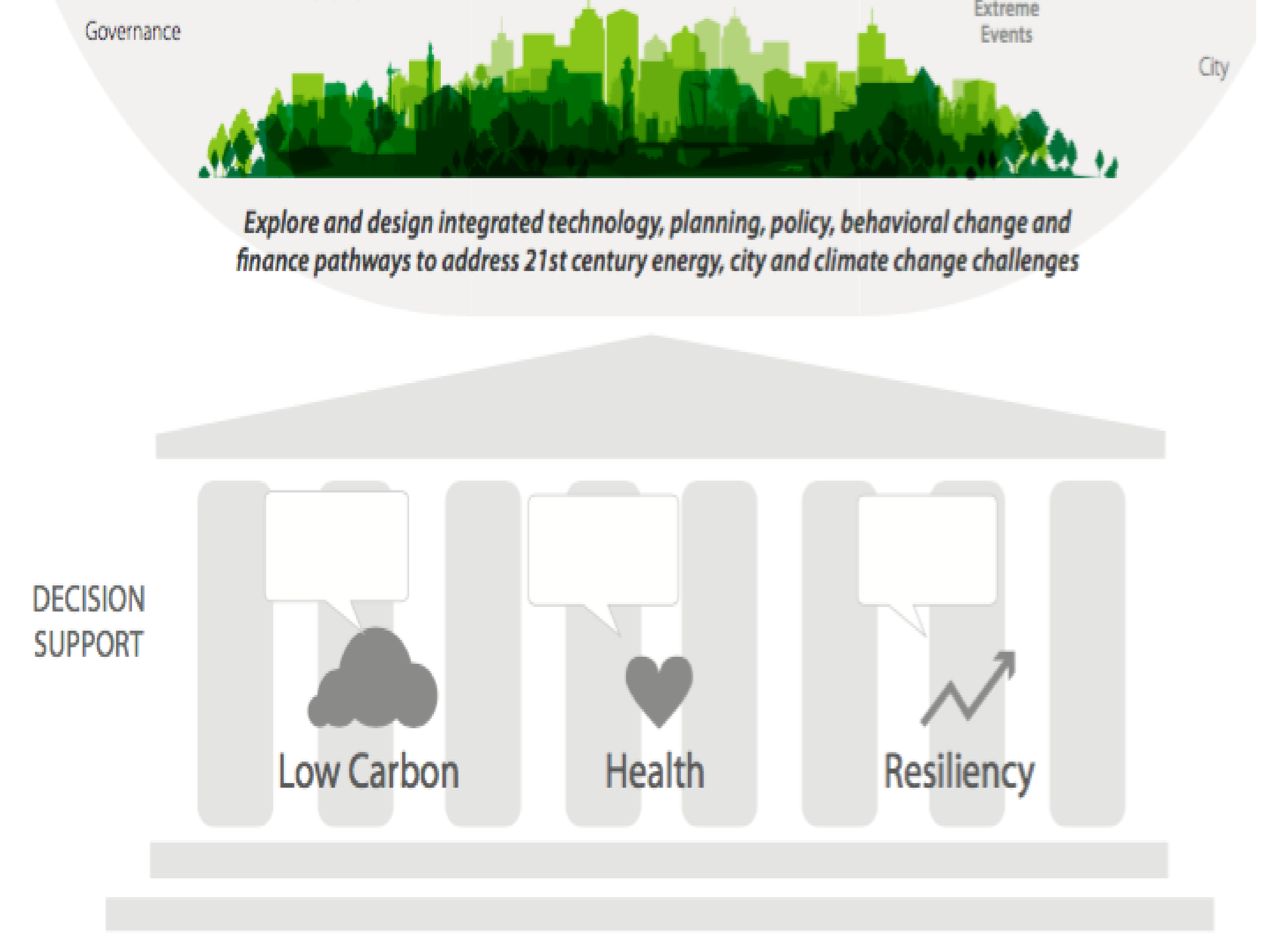
Training …capacity building at the science-policy interface

Optimize …to guide design of human-centered energy systems & urban services

URBAN NEXUS INNOVATION

AN INNOVATION PROCESS ACROSS SYSTEMS, SCALES and CONTEXTS




Governance
Extreme
Events
City
Explore and design integrated technology, planning, policy, behavioral change and finance pathways to address 21st century energy, city and climate change challenges
DECISION
SUPPORT
Low Carbon
Health
Resiliency

US DOT-DOE-HUD-PCAST-State-etc: Technologies and the Future of Cities

SMART Mobility

Systems and Modeling for Accelerated Research in Transportation

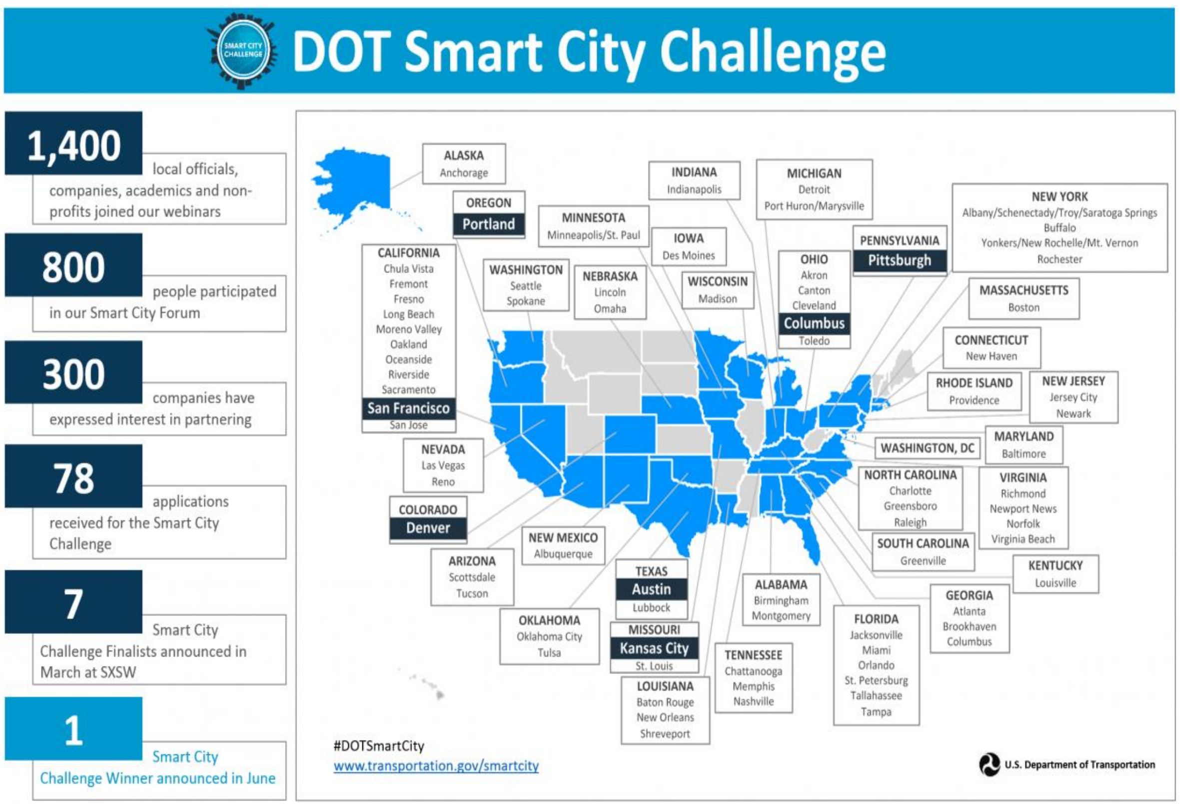
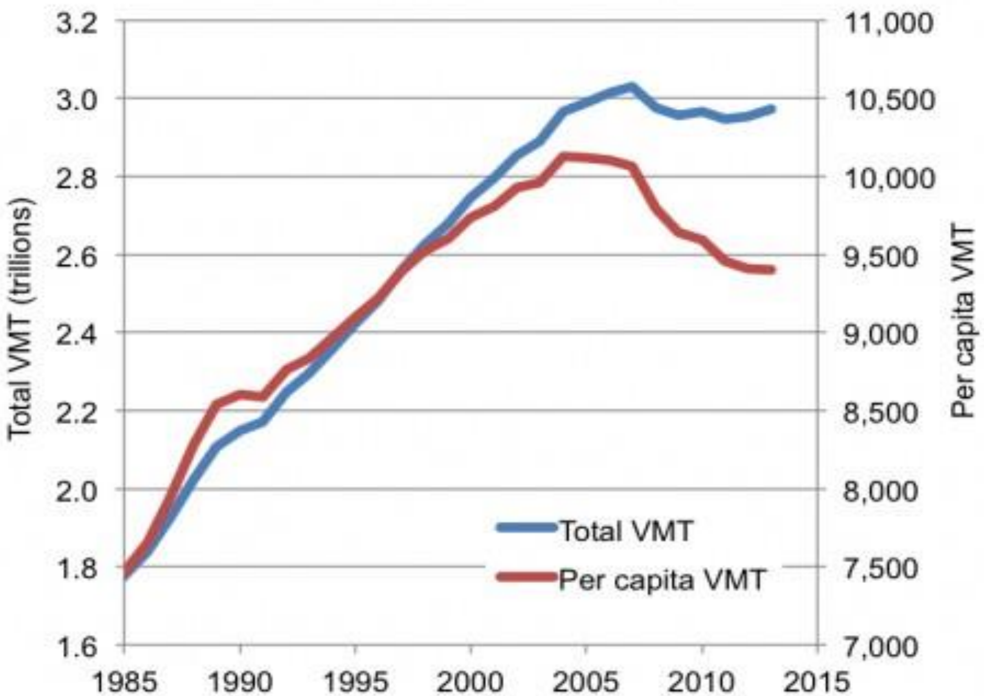


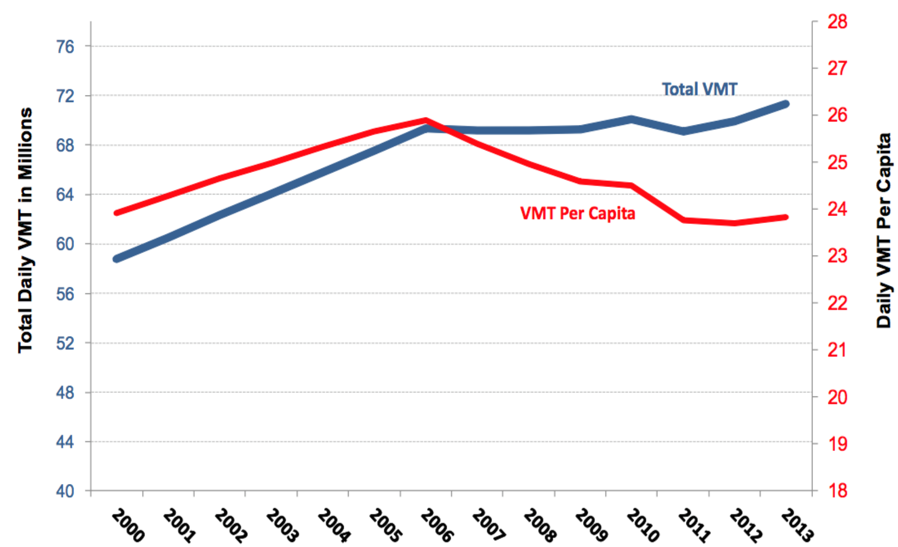
Figure 1 - Five Pillars of Proposed DOE Transportation System Framework

VMT Trends for US & Denver



Denver total VMT continuing to increase due to rapid population growth and auto-dependency (transit hovers at ~4%

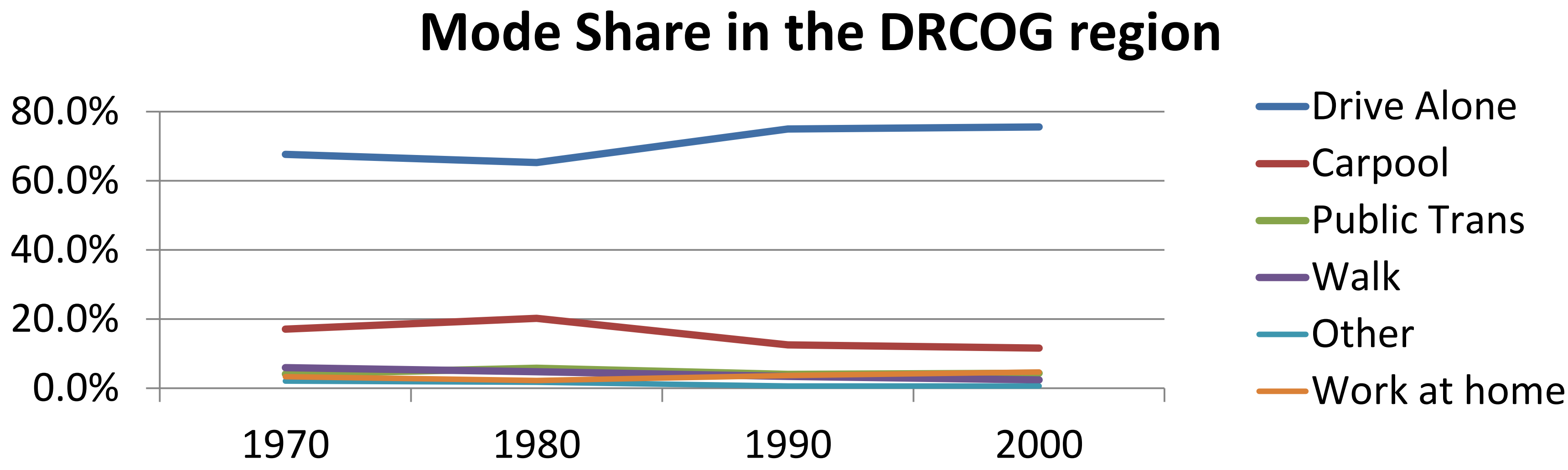
Figure 2 - Denver Region Weekday VMT (2000 - 2013)



Sources: Colorado Department of Transportation, Denver Regional Council of Governments, Federal Highway Administration

US VMT hovering around 3 trillion miles from 2012-2015; while VMT/capita now dropping

More driving alone; public transit hovering at 4% since 1970s

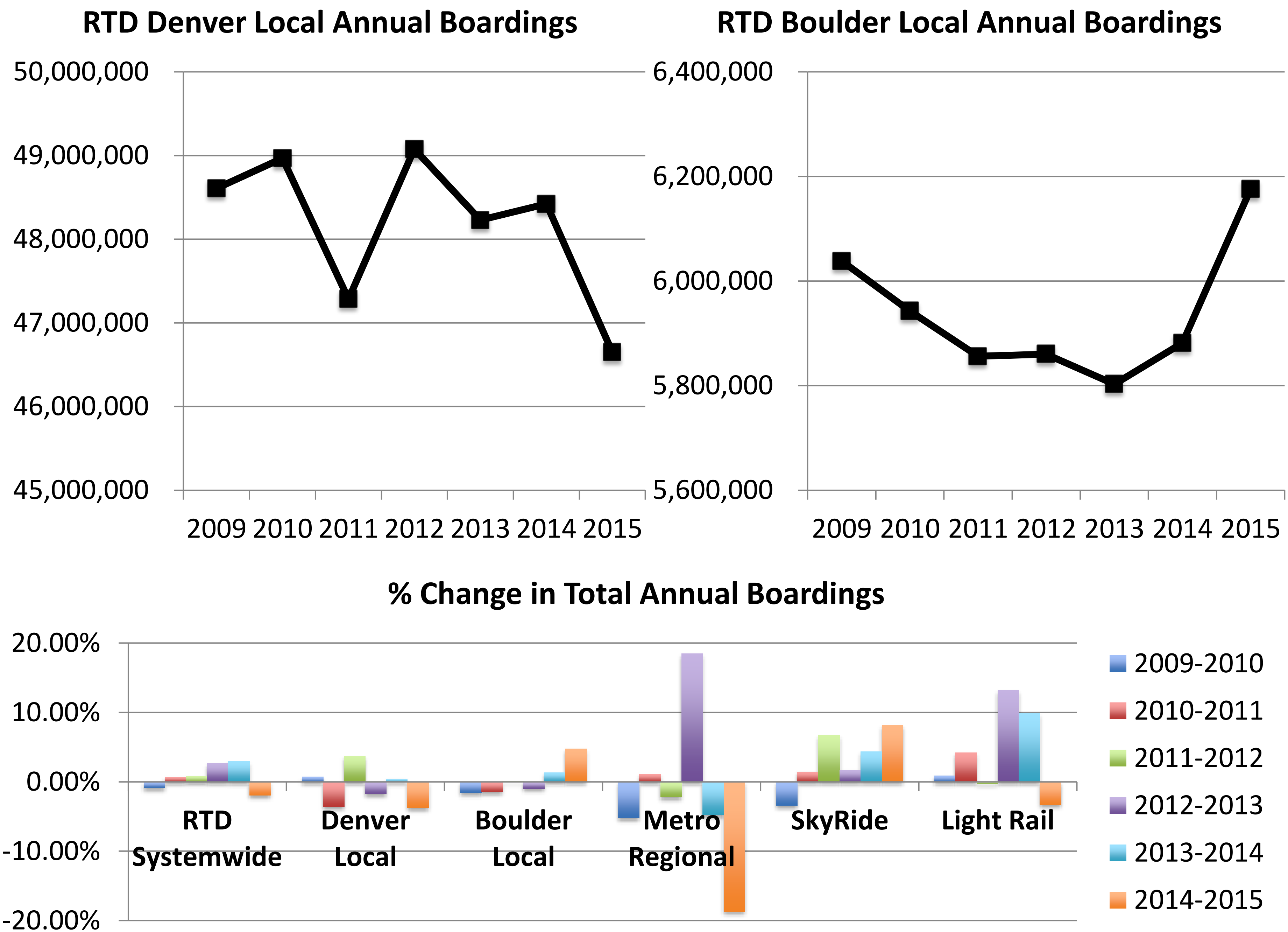


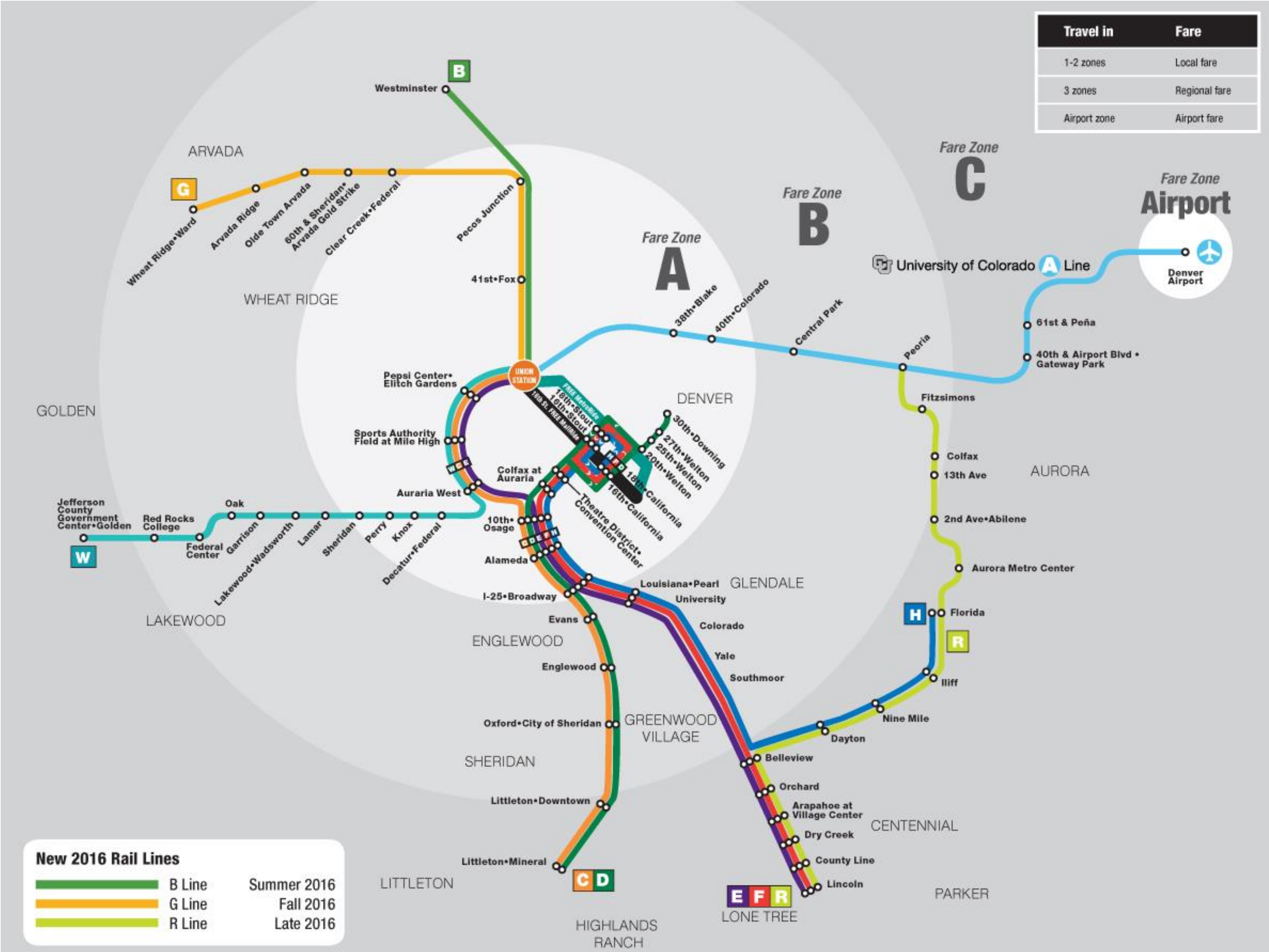
	Denver-Aurora-Boulder, CO CSA									
	2009		2008		2007		2006		2005	
Drove alone	**1,164,815**	***75.0%***	**1,186,844**	***73.9%***	**1,148,023**	***74.9%***	**1,123,394**	***75.3%***	**1,014,508**	***76.8%***
Carpooled	142,457	***9.2%***	170,193	***10.6%***	150,258	***9.8%***	148,067	***9.9%***	120,521	***9.1%***
Public transportation	68,665	***4.4%***	73,826	***4.6%***	68,996	***4.5%***	63,332	***4.2%***	52,842	***4.0%***
Bicycle	17,370	***1.1%***	17,473	***1.1%***	15,679	***1.0%***	14,581	***1.0%***	11,358	***0.9%***
Walked	36,149	***2.3%***	36,813	***2.3%***	40,408	***2.6%***	37,454	***2.5%***	32,868	***2.5%***

Emerging Investments & Study Design

- University of Colorado A’ rail line
  - Received nearly $1.5 billion in public-private investment and connects Denver Int’l Airport and Downtown (opened April 2016), offering new alternative mode for urban-regional travellers.
- Exploring new urban rail transit innovation and new ‘GoDenver’ mobility app innovation
  - Design of experiment exploring varied incentives for, as well as enablers /barriers to traveller adoption (including business travelers and residents) of new infrastructure, more affordable housing near transit, and information systems that integrate ridesharing-rail services.

Preliminary Results – with RTD

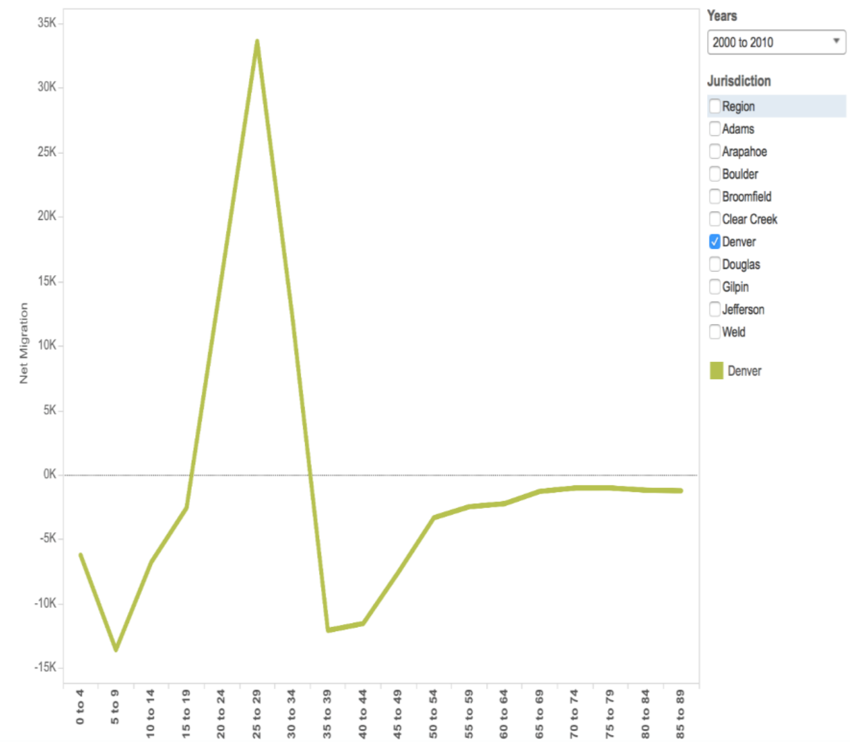




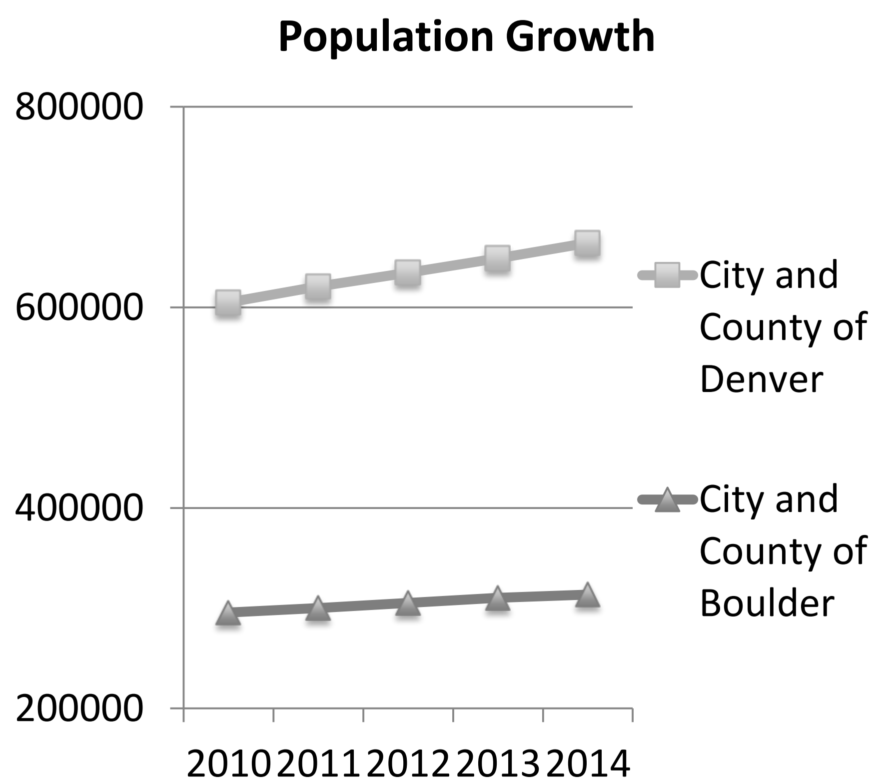
Travel in	Fare
1-2 zones	Local fare
3 zones	Regional fare
Airport zone	Airport fare

Denver Metro Area: Key Challenges

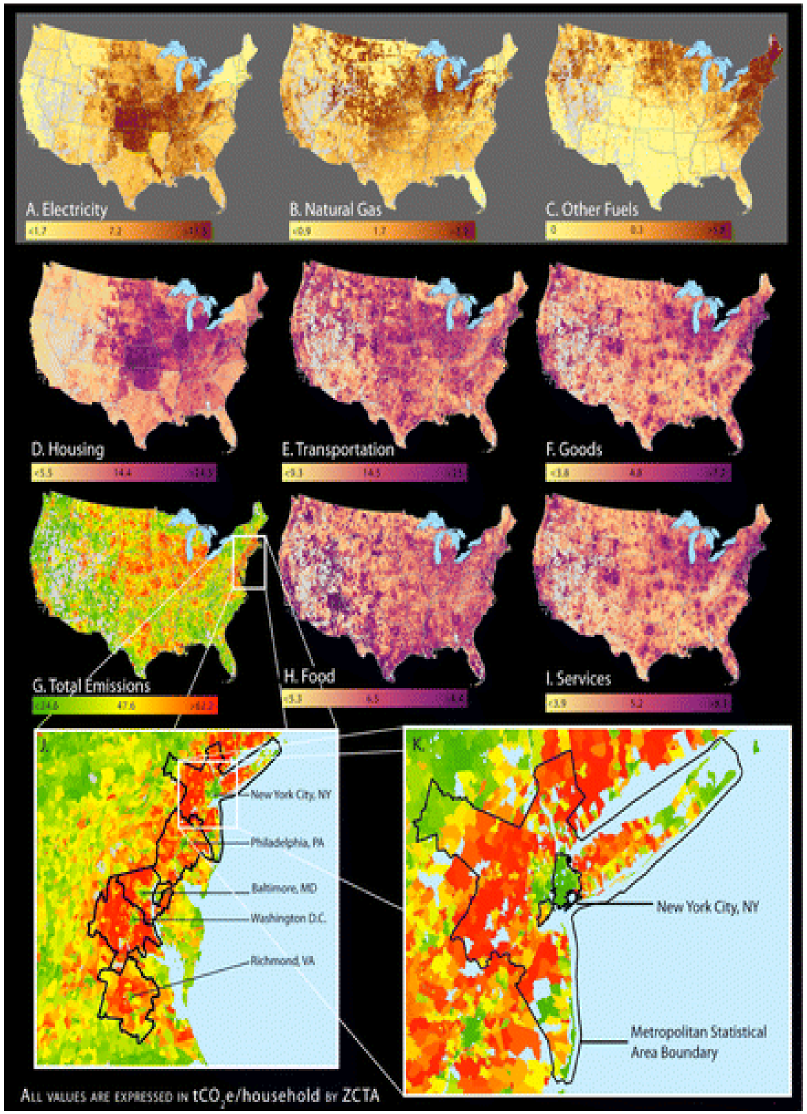
- Sprawl, auto dependency; lack of affordable housing
- Rapid population growth
- Shifting demographics/mobility options
- QoL/Energy/GHG implications?

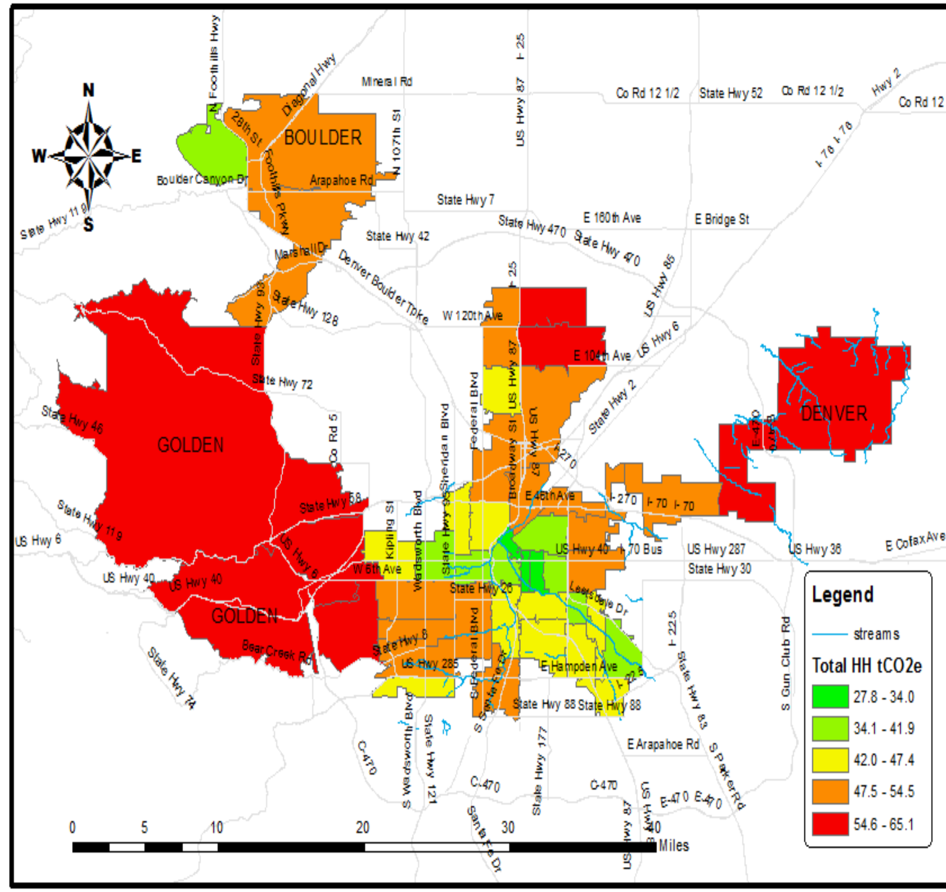


"Demography Dashboard" *Colorado Department of Local Affairs*. 2015. https://dola.colorado.gov/demog_webapps/dashboard.jsf



Mapping mtCO2e/household in Denver Metro



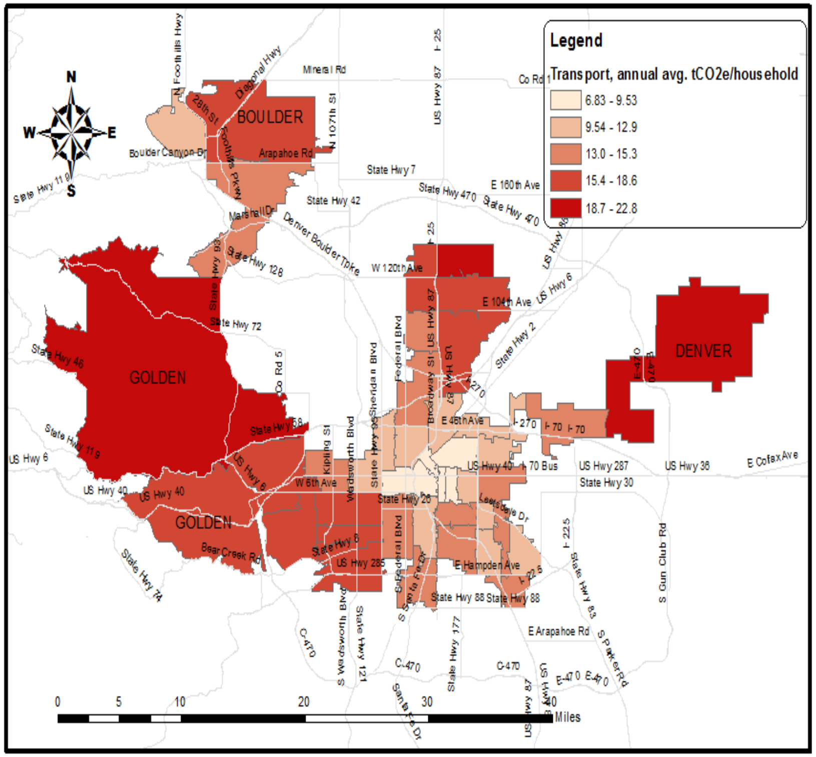


Denver Metropolitan Region, Initial Energy Analysis:
Avg. Annual Household Total tCO2e by Zip Code

Data Sources: Berkeley Cool Climate; Zip Code Tabulation Area (Available at census.gov); Streams data from data.denvergov.org; TIGER roads data at data.gov

Methods / Transportation tCo2e/household

- We use existing national household survey data to develop econometric models of demand, for transportation, residential energy, food, goods, and services.
- Independent variables used to predict household electricity, natural gas and other household heating fuels in the Residential Energy Consumption Survey(19) (*n* = 4363) include energy prices, heating fuel type, heating and cooling degree days, structure of homes (number of rooms, percent single-detached, year home-built), demographic information (income, number of household members, age of householder, race), home ownership, percentage rural or urban, Census divisions, and U.S. state.
- Predictive variables for motor vehicles miles traveled (VMT) in the National Household Travel Survey(20) (*n* = 11 744) include number of vehicles owned, fuel prices, average time to work, percentage of commuters who drive to work, demographic information (income, number of household members, race), number of food and recreation establishments in the zip code, population density, Census region, and U.S. state. Independent variables for 13 categories of goods and 11 categories of services in the Consumer Expenditures Survey(21) (*n*= 6965) include household size and income.



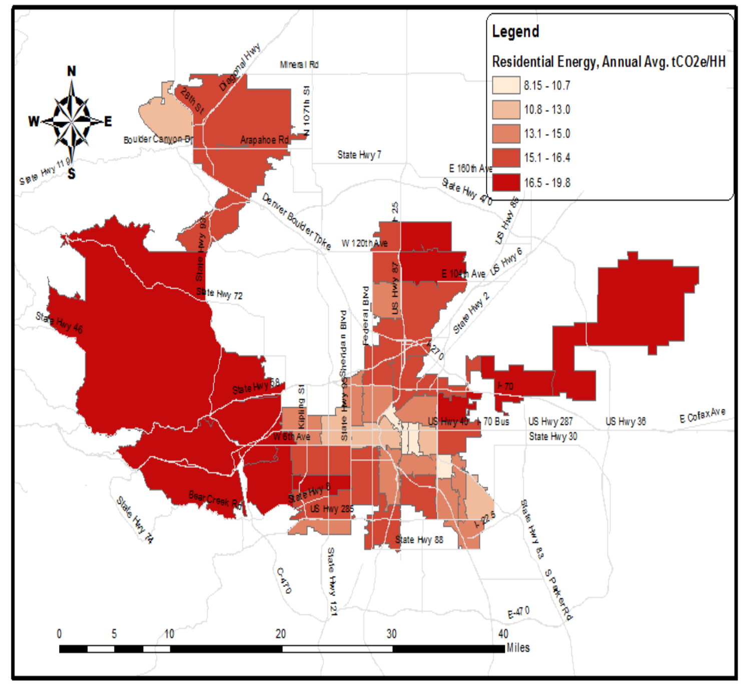
Denver Metropolitan Region, Initial Energy Analysis: Avg. Annual Household Total tCO2e by Zip Code

type	city-scale metric	national bench-mark	Denver, CO	Boulder, CO	Fort Collins, CO	Arvada, CO	Portland, OR	Seattle, WA	Minneapolis, MN	Austin, TX
Transport	Road (VMT/ capita/day)	(27)	24 *[28]*	24 *[28]*	25 *[28]*	13 *[28]*	22 *[26]*	25 *[24]*	17 *[30]*	26 *[28]*
	Airline (enplaned passenger/ capita)	(2.3)	8	6	6	3	4	4	7	3
	Jet fuel (gallons/enplaned passenger)	(22)	19	19	19	19	26	30	23	17
	Long distance freight truck ($-1997/cap)	($288)	$295	$295	$295	$295	$424	$203	$432	$94
Key urban materials	Municipal solid waste (tons/capita)	(0.82)	1.25	1.07	1.89	1.14	1.02	0.77	0.97	1.07
	Self-reported waste diversion	(33%)	2%	n/a	n/a	n/a	54%	41%	37%	17%
	Gasoline gallons/ capita/yr	(464)	435	433	459	231	400	446	315	447
	Diesel gallons/ capita/yr	(148)	69[b]	71[b]	73[b]	37[b]	115[b]	128[b]	90[b]	158[b]
	Jet fuel gallons/ capita/yr	(65)	149	112	107	56	112	111	148	56
	Cement mt/ capita/yr	(0.36)	0.50	0.72	0.46	0.50	0.25	0.32	0.32	0.67
	Food ($-1997/ HH/yr)	($4,841)	5,463	5,463	5,463	5,463	5,474	5,979	5,713	5,331
	Treated water/ WW in 1,000 gal/capita/yr		148	129	108	91	97	96	104	122

[a] Corresponding state benchmarks are shown as in brackets, []; multi-state regional benchmarks are shown in braces, {}; national benchmarks are shown in parentheses, (). [b] Does not include long distance freight, which is included as economic activity. [c] Estimation error up to 10% because of differences in residential–commercial designations between cities, census, and utilities. National/State Data Sources: cement (*17*), VMT (*30*), commercial energy (*31*), residential energy (*32*), jet fuel use and enplaned passengers (*33*), state energy data (*34*), and MSW (*35*).

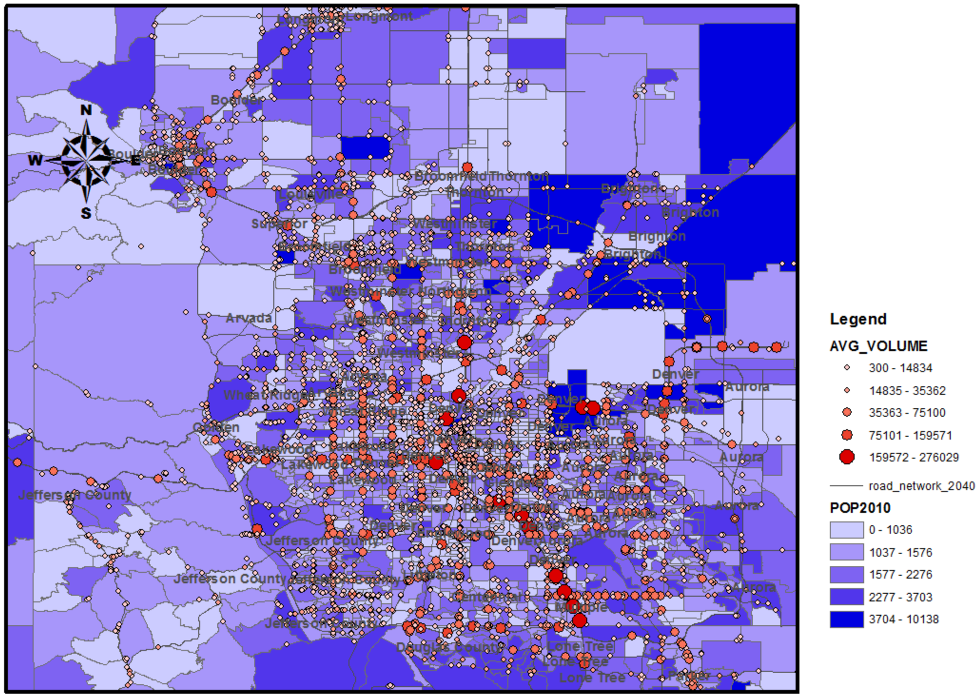
Residential Energy

type	city-scale metric	national bench-mark	Denver, CO	Boulder, CO	Fort Collins, CO	Arvada, CO	Portland, OR	Seattle, WA	Minneapolis, MN	Austin, TX
Demographic	Population (capita)	n/a	579,744	101,547	125,740	104,830	682,835	575,732	387,711	672,011
	Population density (capita/sq mile)		3,789	4,231	2,733	3,276	5,096	6,937	7,180	2,677
	Number of homes (HH)		256,524	45,949	54,908	41,110	294,325	276,794	172,316	281,176
	Square feet per home (sf/HH)		1,107	1,458	1,684	1,442	1,278	1,321	1,683	1,321
	Total commercial floor area (million sf)		229	35	30	23.4	153	269	210	314
	Total floor area per capita (sf/cap)		802	1004	975	789	992	1102	1289	1020
Buildings and facilities energy use[c]	Residential (kWh/HH/mo)	(888)	545 *[667]*	444 *[667]*	689 *[667]*	687 *[667]*	765 *[981]*	740 *[1043]*	478 *[805]*	1108 *[1170]*
	Residential (therms/HH/mo)	(58)	45 *[57]*	38 *[57]*	51 *[57]*	55 *[57]*	30 *[26]*	28 *[29]*	60 *[59]*	26 *[21]*
	Residential (kBtu/HH)	(8,830)	6,377 *[7965]*	5,283 *[7965]*	7,423 *[7965]*	7,881 *[7965]*	5,629 *[5946]*	5,316 *[6410]*	7,585 *[8663]*	6,423 *[6054]*
	Commercial-industrial electricity (kWh/sf)	(14)	15	22.6	16	12	20	16	16	18
	Commercial-industrial thermal (kBtu/sf)	(90)	69	47	45	44	43	43	71	20
	Commercial-industrial total (kBtu/sf)	(138)	122 *{104}*	125 *{104}*	100 *{104}*	85 *{104}*	110 *{69}*	97 *{69}*	124 *{80}*	81 *[73]*

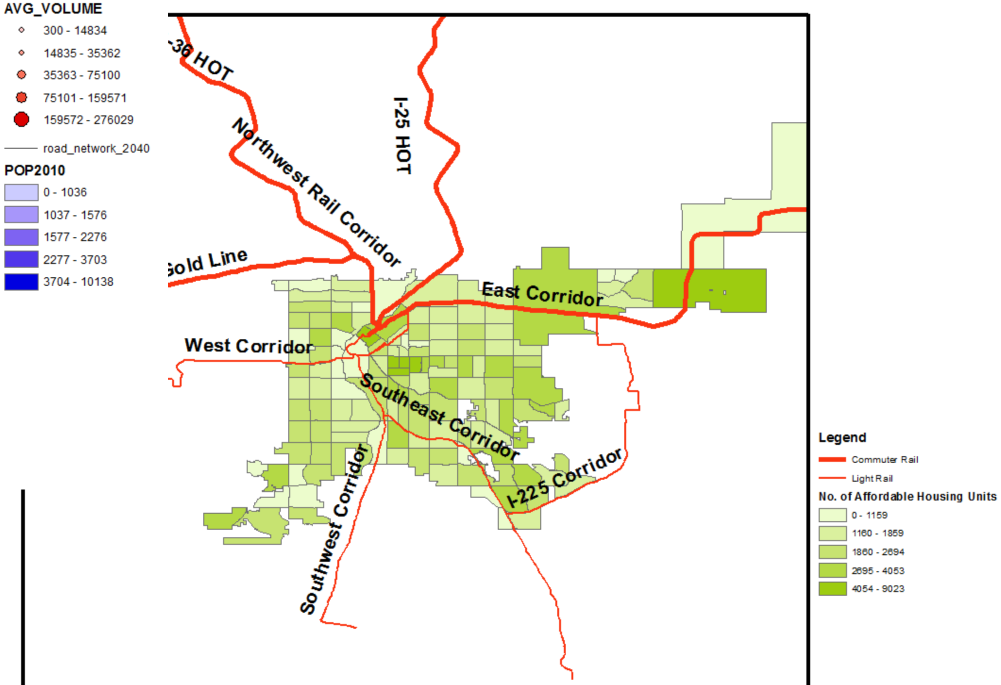


Denver Metropolitan Region, Initial Energy Analysis:
Avg. Annual Resid. Energy:Total tCO2e/HH by Zip Code

Auto-Dependency vs. Transit Ridership (considering affordable housing)



Denver Regional Traffic Counts
Avg. Daily Volume (2013-2014)



Denver Affordable Housing Near (2035) Regional Transit

Overarching Questions

- This study helps answer three key questions:
  - What are the experiences and levels of satisfaction with new infrastructure and information systems and services in the Denver metro region?
  - How can companies and cities in Denver best incentivize the use of new transit investments, ride-sharing services, and integrated mobility mobile apps?
  - What are the potential co-benefits (e.g. energy use, vehicle miles traveled, personal convenience, social) of new hybrid models?

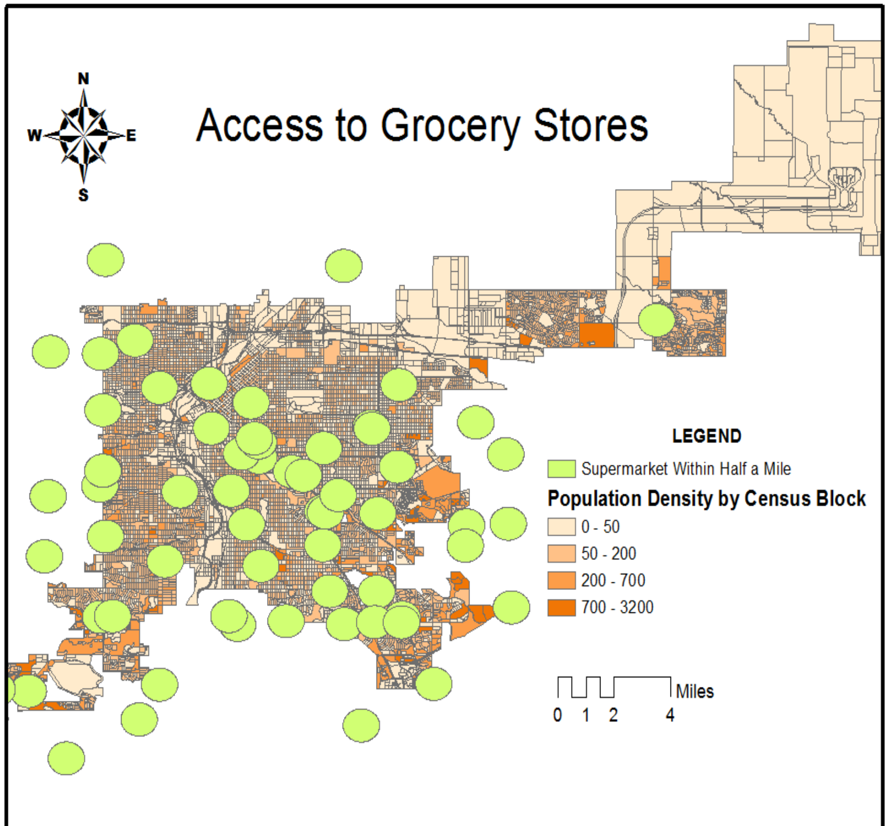
City-Region Data Foundations for CAVs, Shared Economy, Electrification, & Multimodal Solutions

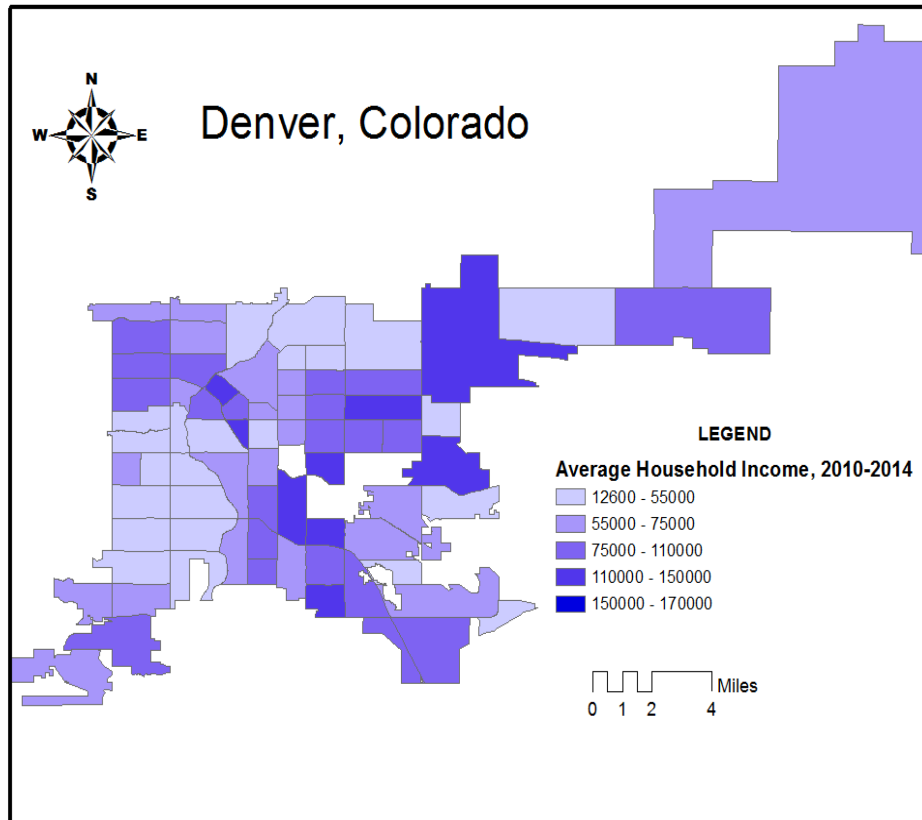
- A pretest survey in select locations (e.g. DIA, Panasonic/PenaNext, Denver Tech Center, first and last mile challenged areas of the new West Corridor rail line, and Union Station) will be used to refine survey questions
- Results will help best design future incentive-based experiments in diverse settings. A total of 100 travelers some of whom are using ridesharing, to and from RTD study sites, or on a relevant RTD rail line were surveyed as part of the pretest/preliminary study

Initial Pretest Survey Responses

- Survey Participant is…
- Coming from? ____ and going to? __ _ _ ___ (please mark on map)

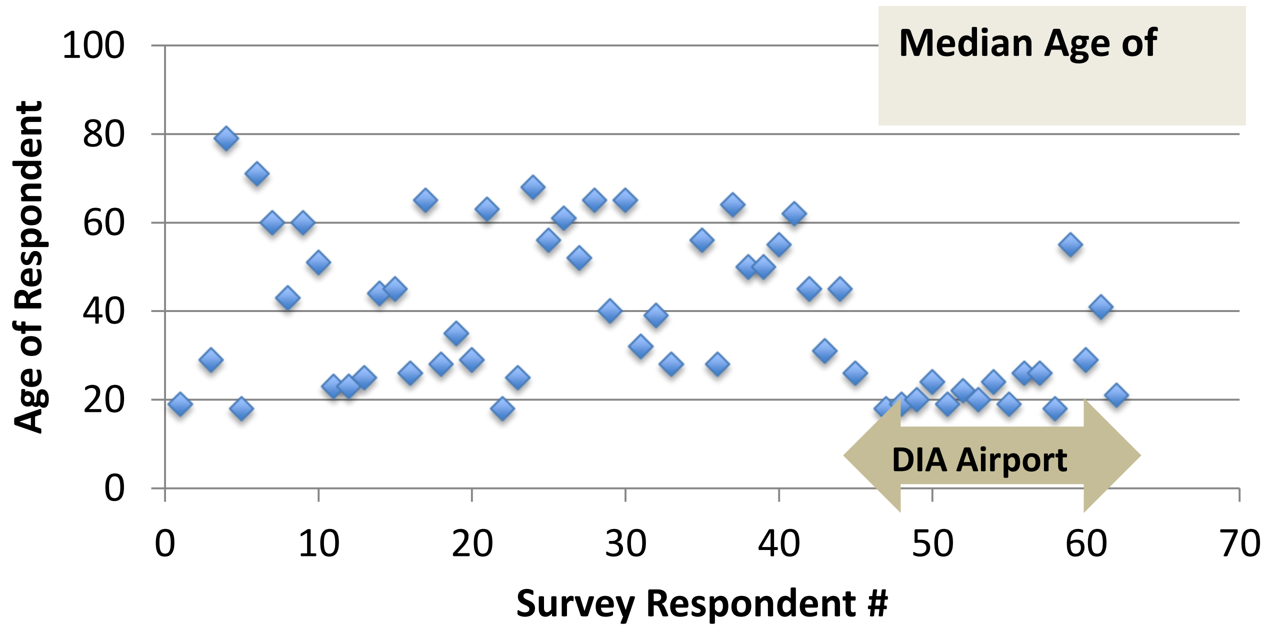
Survey Respondents Profile	
Traveling for Work	56%
Traveling for Pleasure	44%
A DIA Employee	37%
A CO Resident	74%
A CO Visitor	26%
Gender (% Male)	48%
Not using transit and only drives	10%

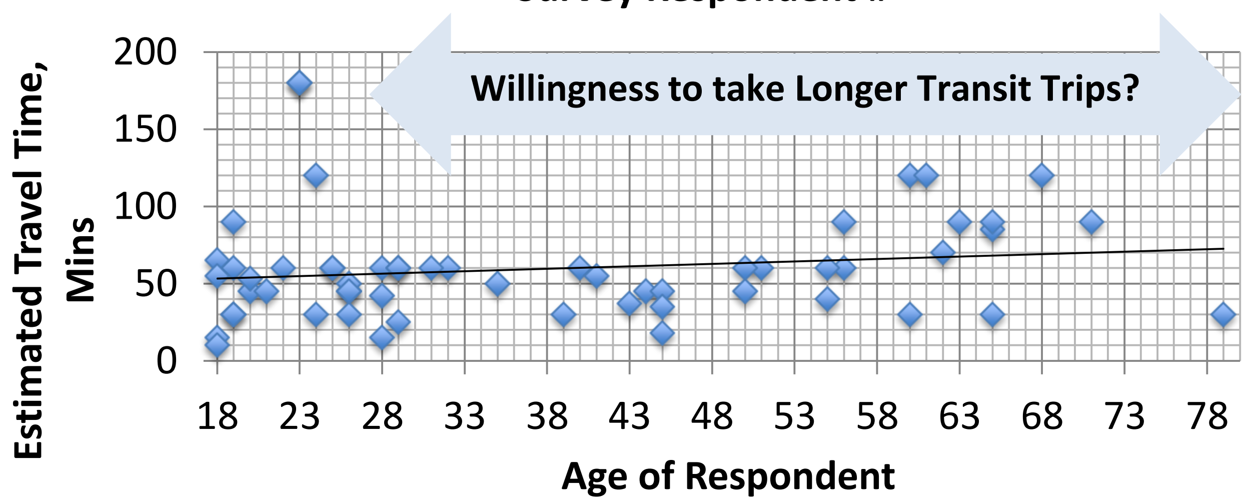




Motivations, Age, and Willingness

Public Transit Travel Choice Motivated By:	
Energy/Environmental concerns	50%
Cost/Financial concerns	61%
Convenience	94%
Time	65%





Perhaps a Future Emerging Trend:

More Travelers with Smart Phones than Private Motor Vehicles?

- Have you used the GoDenver mobility app to plan at least part of your trip from origin to destination? 1 Yes 2 No; B) If Yes, how did the GoDenver app influence your travel decisions: _____________
- Did you make your decision prior to or after using GoDenver app? 1 Y 2 N
- Did the GoDenver mobility app information inform your travel mode choice? 1 Y 2 N

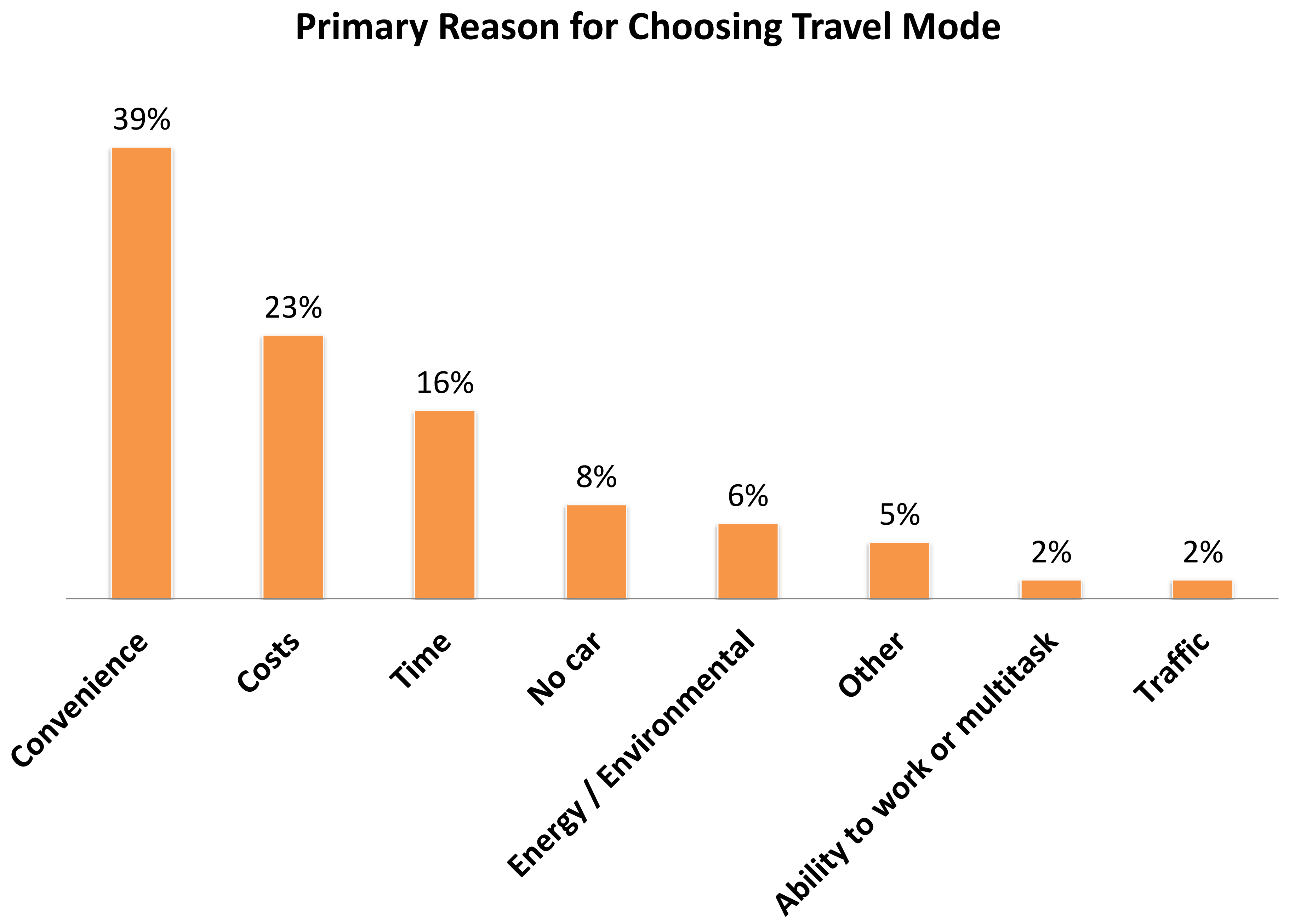
If mobility app informed your decision, was travel mode choice informed primarily by the

1 Sooner 2 Cheaper 3 Greener 4 Healthier options list?

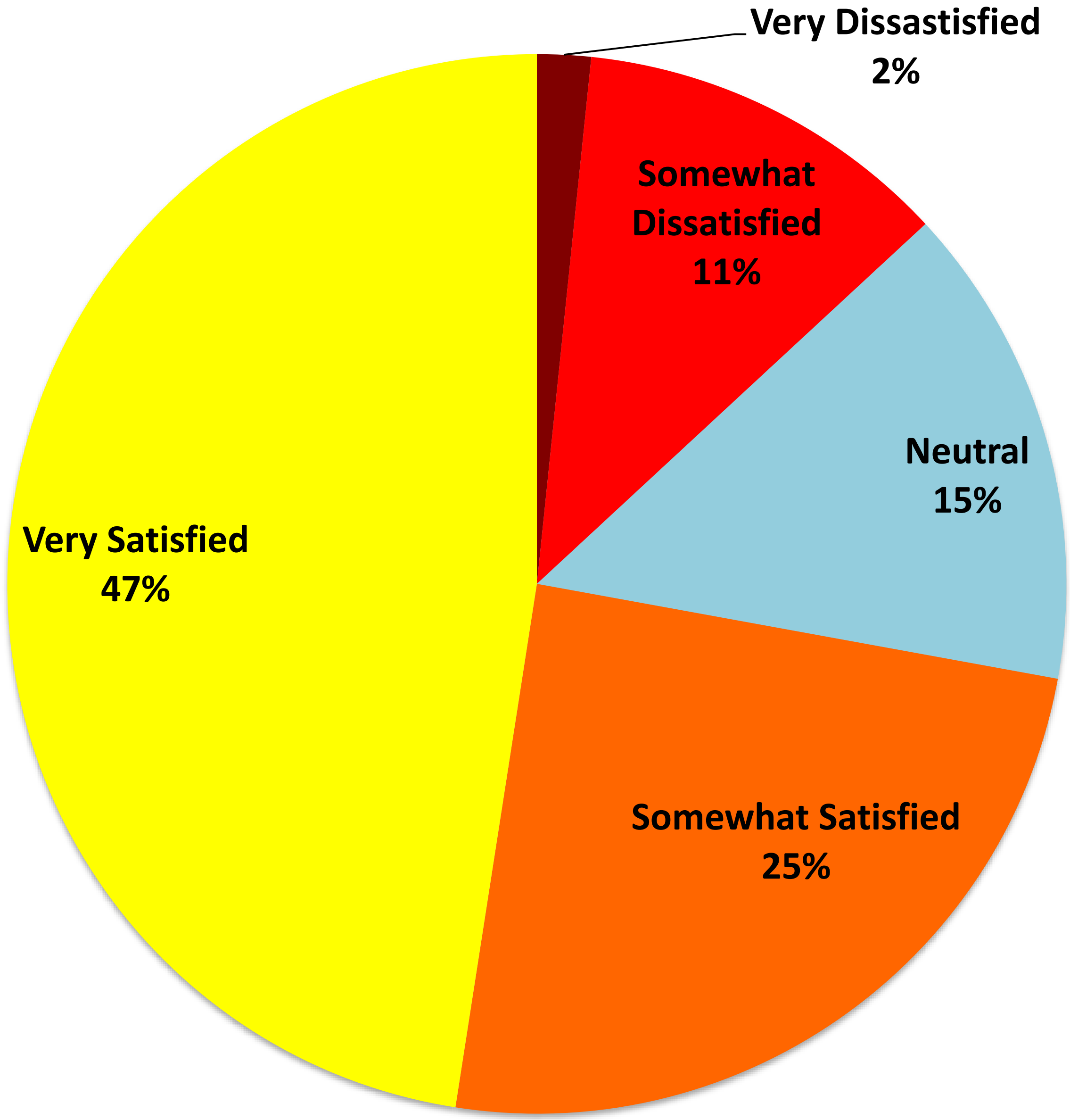
C) [If "No to using Go Denver app"; survey participant gets demo at the end of the survey]: If you could use the app in future , would it improve your experience**?** 1 Yes 2 No; Comments: ______;

Rank: ___ sooner, __cheaper, ___greener, ___ healthier as information that is most useful to daily trips.

Survey Respondents Profile	
Have a Smart Phone	88%
Using Uber/Lyft	29%
Have a Motor Vehicle	79%
GoDenver Travel Priority #1: Cheaper	41%
GoDenver Travel Priority 1: Sooner	45%
GoDenver Travel Priority 1: Greener	14%
GoDenver Travel Priority 1: Healthier	0%


Primary Reason for Choosing Travel Mode
39%
23%
16%
8%
6%
5%
2%
2%
Convenience
Costs
Time
No car
Energy / Environmental
Other
Ability to work or multitask
Traffic

Satisfaction with this Segment of Your Trip



…

- What might improve your experience? Please write Y or N

○___ Access to wifi/internet on transit
○___ Access to a bathroom on-board transit
○___ Access to a public bathroom closer to transit station
O__ Cleaner facilities than current O ___ More space for bags/luggage on transit
O___ Device charging outlets on transit
___ Availability of food and beverage for purchase on board
O ___ Express Route
O ___ Alternative payment systems
O __ public drinking water
O___ [weather protection / shelters]
O ___ improve design to carry bikes
O___ Other: please specify: ____________

…

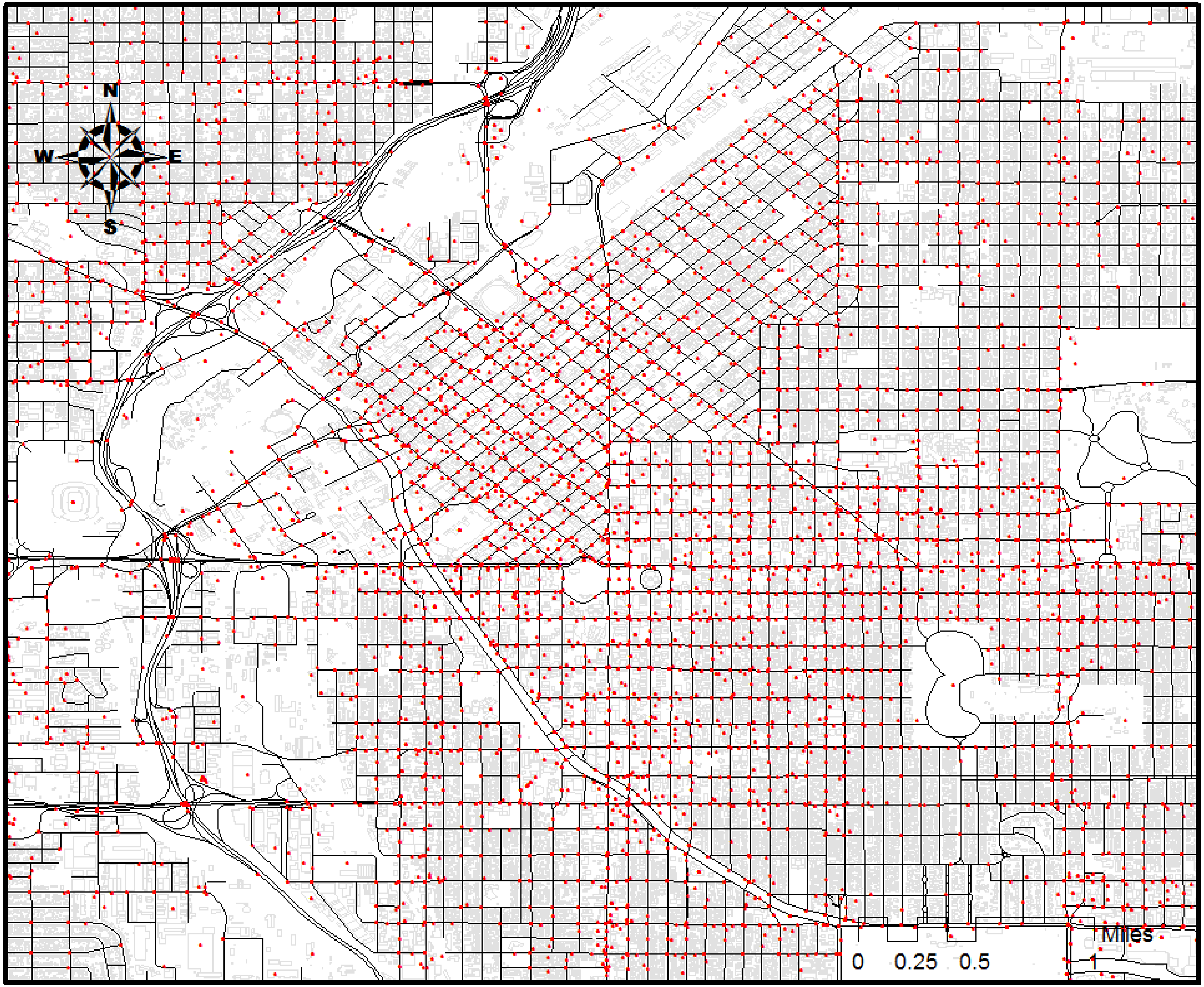
- How often do you do this trip – how many days per week do you make this trip?
- 0 or 1 to 7? ____ Is it one way or both directions? _ _ _
- If not frequent trip, how often? 1-3 months; 3-6 months; once a year? ___ ____
- How many trips did you make to the airport in the previous 60 days? ____
- What travel modes would you use? _______________

…

- If you had not used these travel modes to get to your destination, what would you have done otherwise?
- ○ __ Would have walked ○ ___ Would have driven myself O ___ Would have bicycled
- O __ Would have ridden with someone else O ___ Would have taken a taxi ; O Uber O 2 Lyft
- O ___Would have used the RTD bus O ___ Would have used an airport shuttle
- O ___ Would not have made this trip O ___Other: please specify: _______ ______

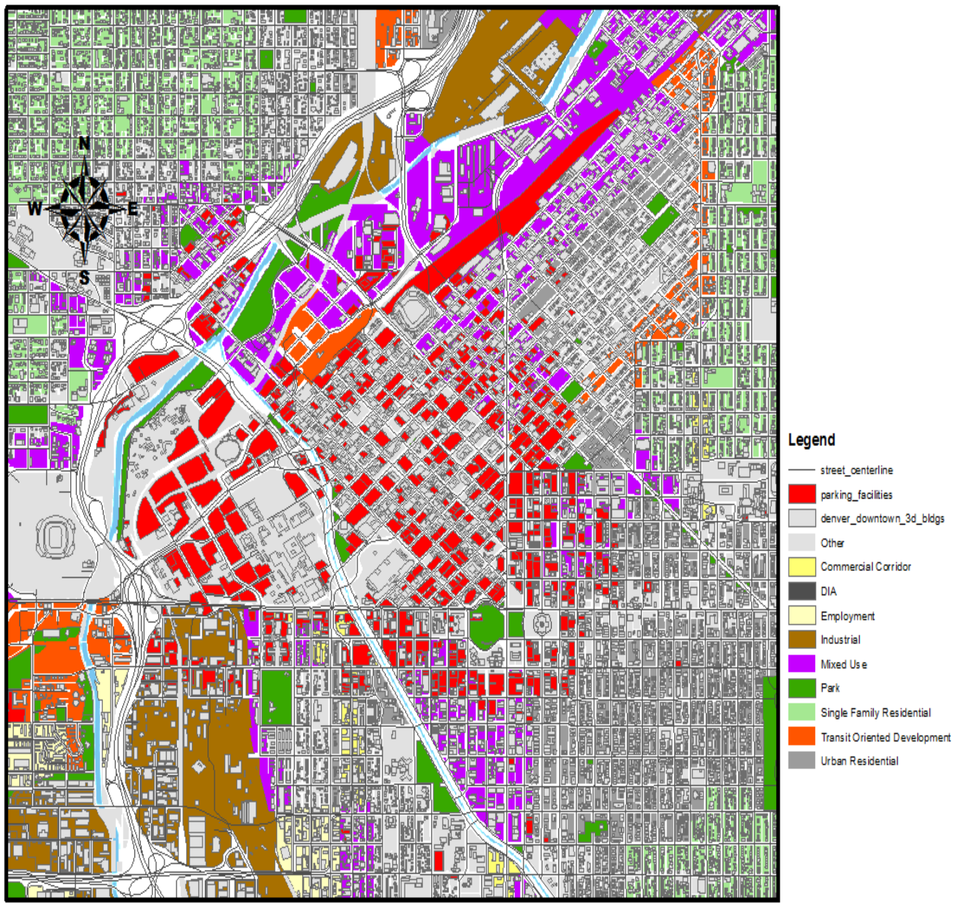
Thank you.

- Questions? Joshuabsperling@gmail.com

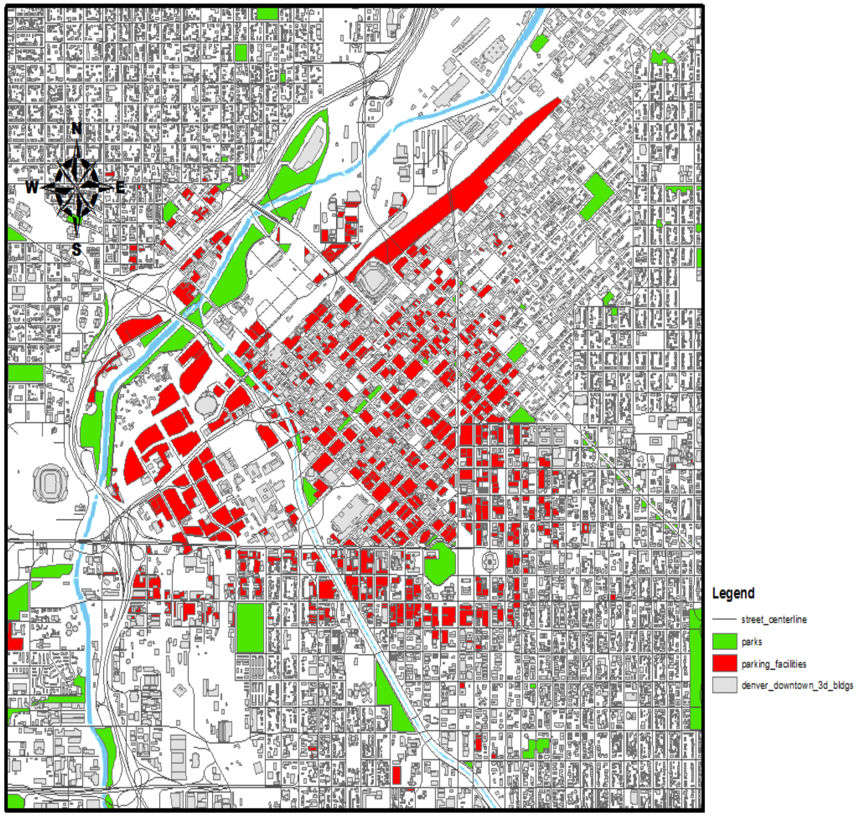


Denver, Colorado

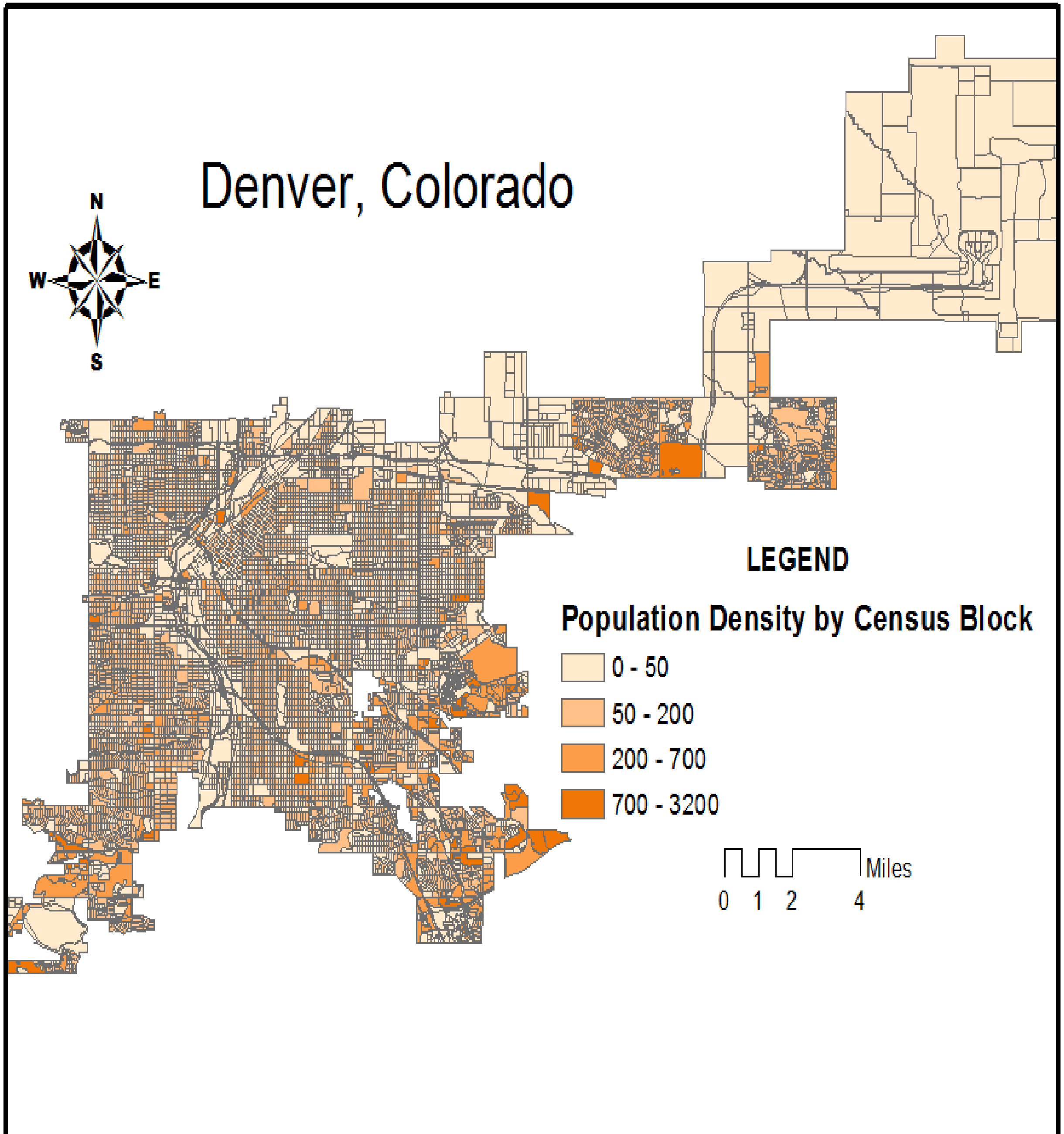
LEGEND
traffic accident occurence

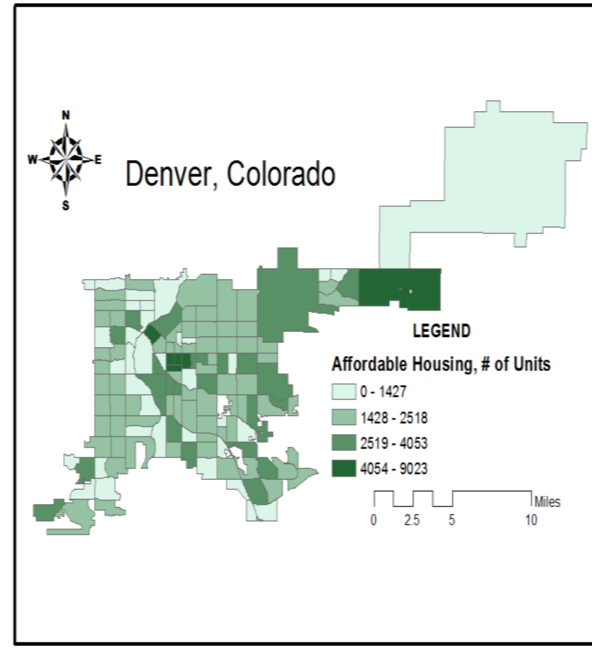


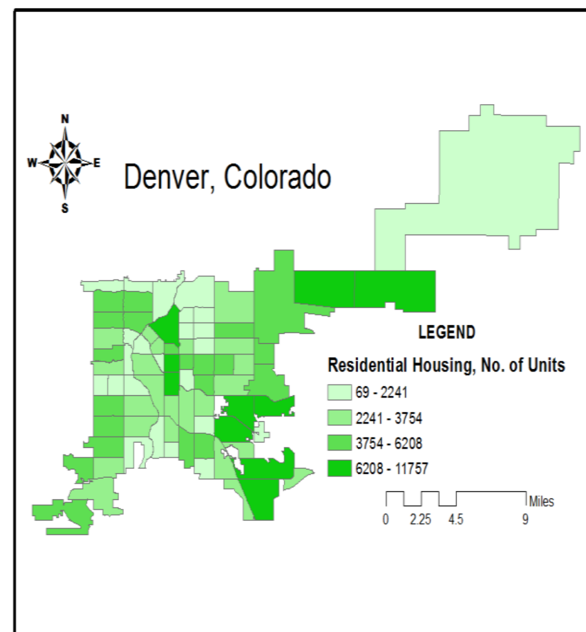
Denver, Colorado

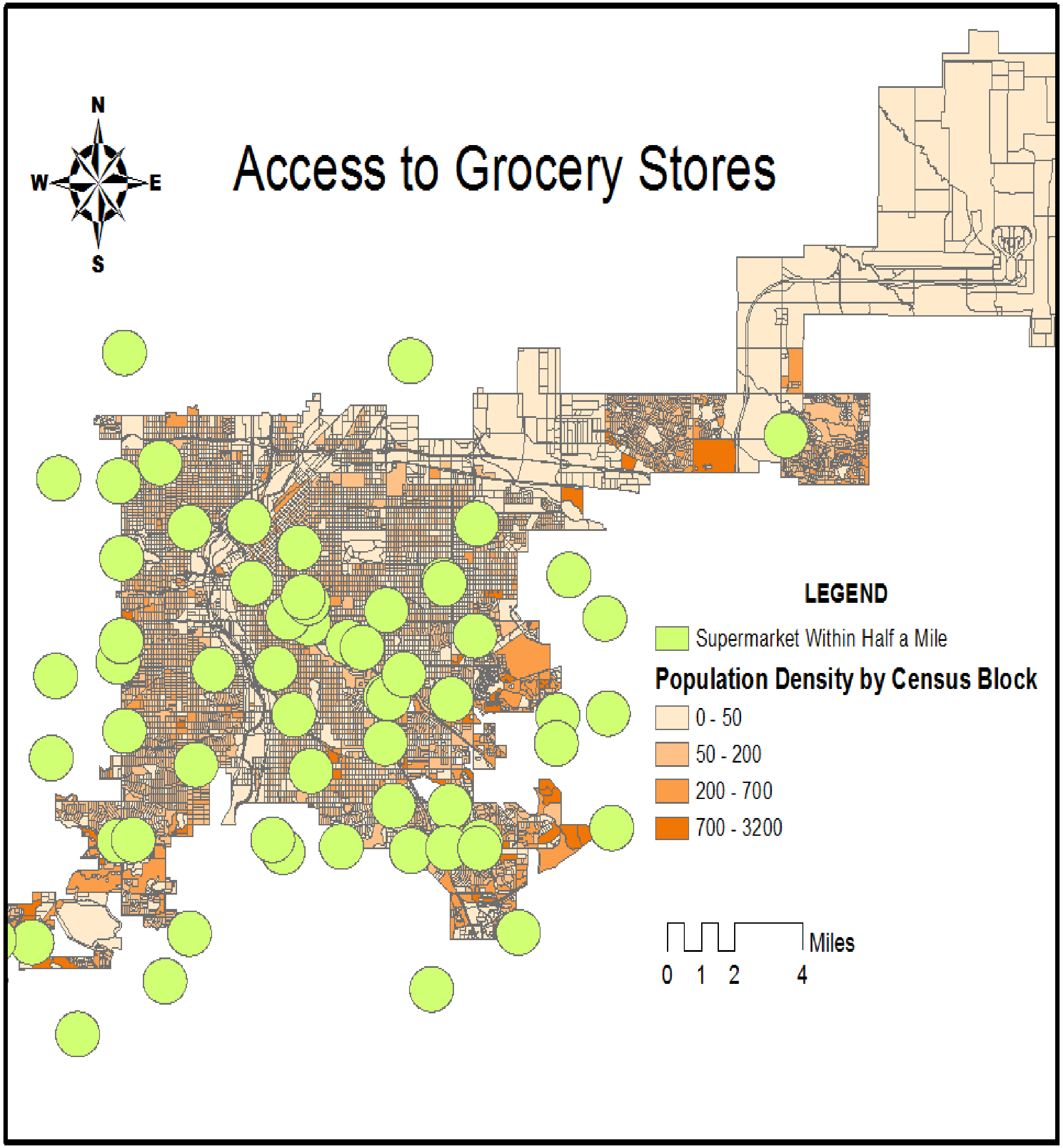


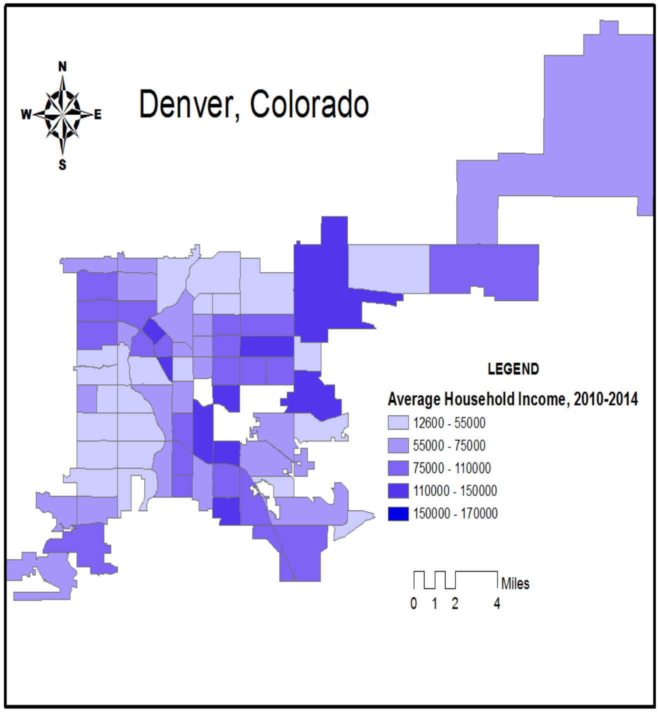
Denver, Colorado

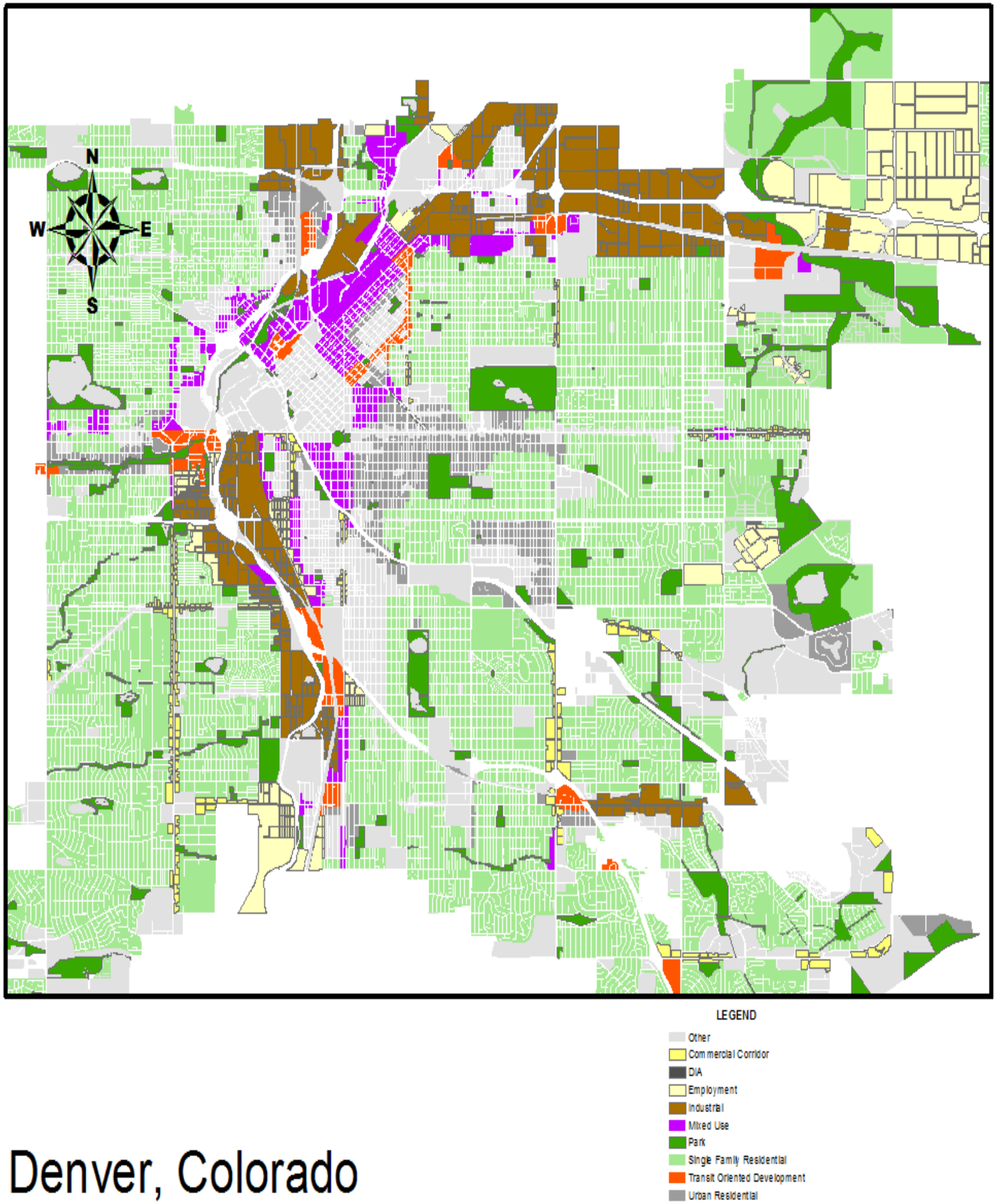

Denver, Colorado
N
W
E
S
LEGEND
Population Density by Census Block
0 - 50
50 - 200
200 - 700
700 - 3200
Miles
0 1 2 4


Denver, Colorado
N
W
E
S
LEGEND
Affordable Housing, # of Units
0 - 1427
1428 - 2518
2519 - 4053
4054 - 9023
Miles
0 2.5 5 10


Denver, Colorado
N
W
E
S
LEGEND
Residential Housing, No. of Units
69 - 2241
2241 - 3754
3754 - 6208
6208 - 11757
Miles
0 2.25 4.5 9

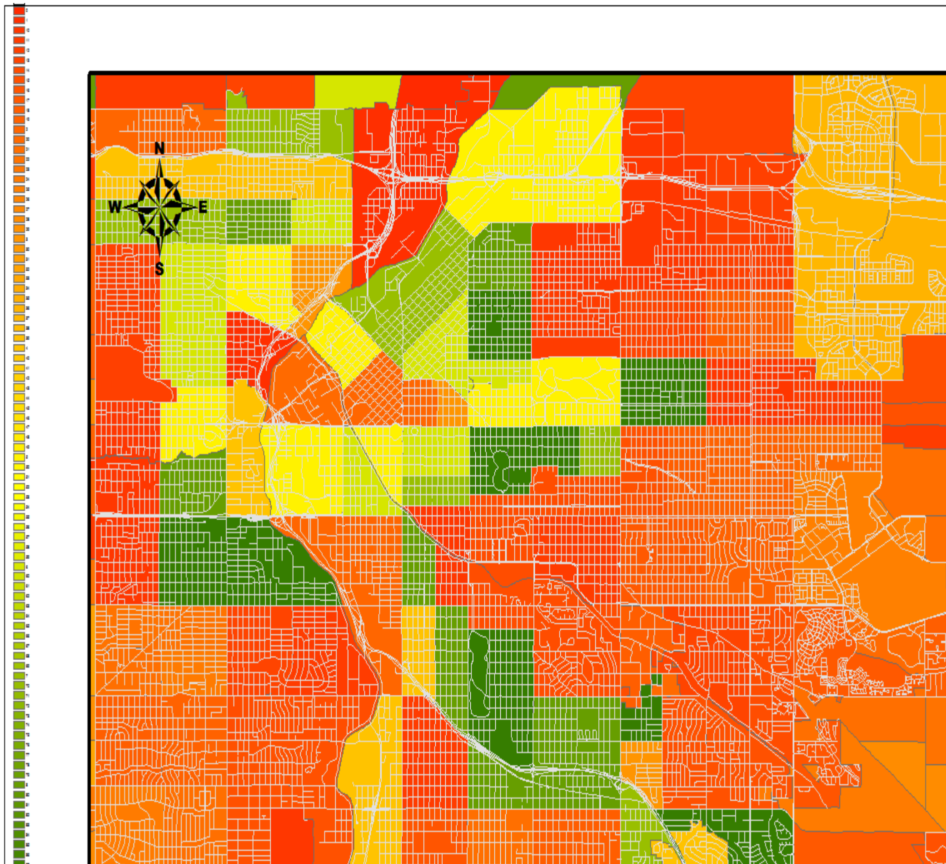

Access to Grocery Stores
N
W
E
S
LEGEND
Supermarket Within Half a Mile
Population Density by Census Block
0 - 50
50 - 200
200 - 700
700 - 3200
Miles
0 1 2 4


Denver, Colorado
N
W
E
S
LEGEND
Average Household Income, 2010-2014
12600 - 55000
55000 - 75000
75000 - 110000
110000 - 150000
150000 - 170000
Miles
0 1 2 4



Denver, Colorado

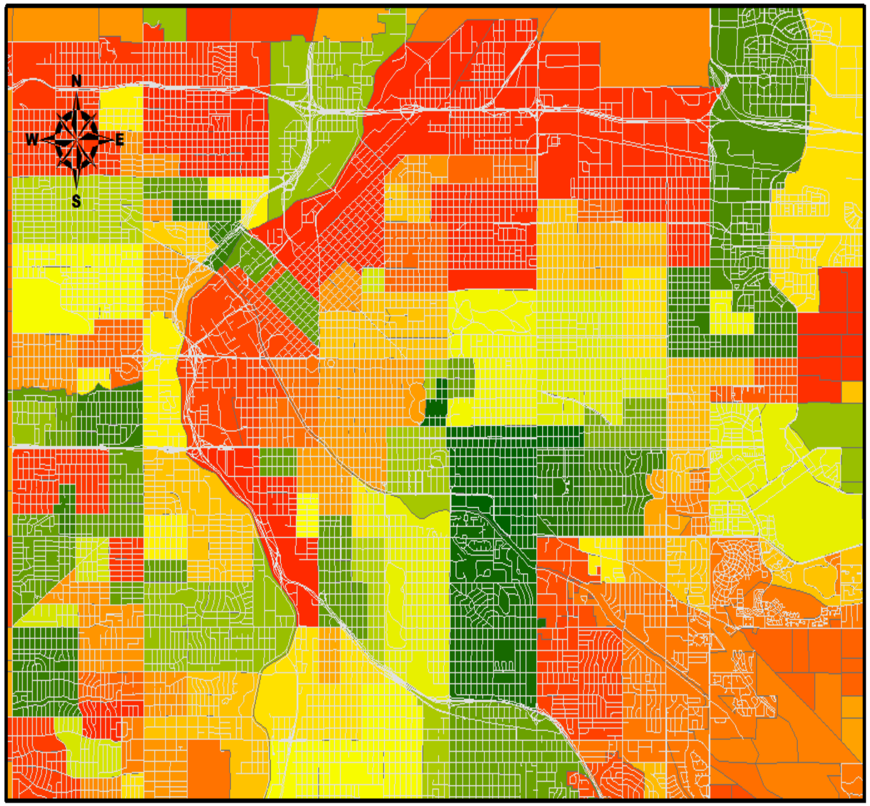
HUD Dataset - National Air Toxics Assessment



Denver, Colorado
Environmental Health Hazard Index by Census Tract

- The environmental health hazard exposure index summarizes potential exposure to harmful toxins at a neighborhood level. Potential health hazards exposure is a linear combination of standardized EPA estimates of air quality carcinogenic (*c*), respiratory (*r*) and neurological (*n*) hazards with *i* indexing census tracts.
- Values range from 0 (worst- red) to 100 (best-green) and percentile ranked nationally. The higher the index value (darker green), the less exposure to toxins harmful to human health. Therefore, the higher the value, the better the environmental quality of a neighborhood, where a neighborhood is a census block-group.
- Dark Green (80-100); Light Green (60-80); Yellow (40-60); Orange (20-40); Red (0-20)
- Data Source: National Air Toxics Assessment (NATA) data, 2005. Data is current as of 6/15/2015.

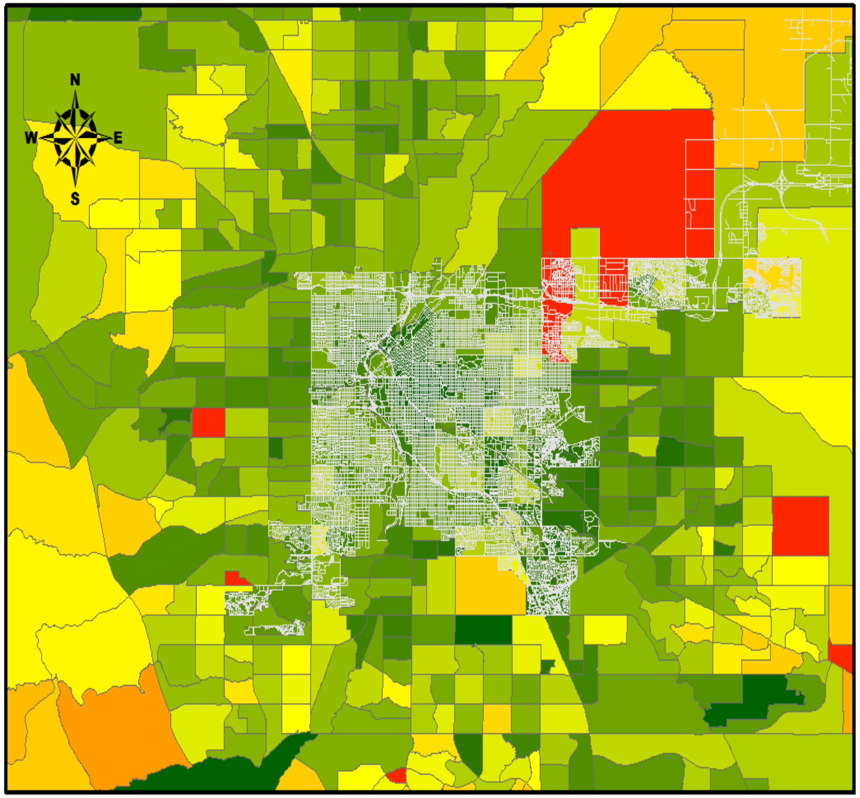
HUD Dataset – School Proficiency (4th Grade)



Denver, Colorado
School Proficiency Index by Census Block

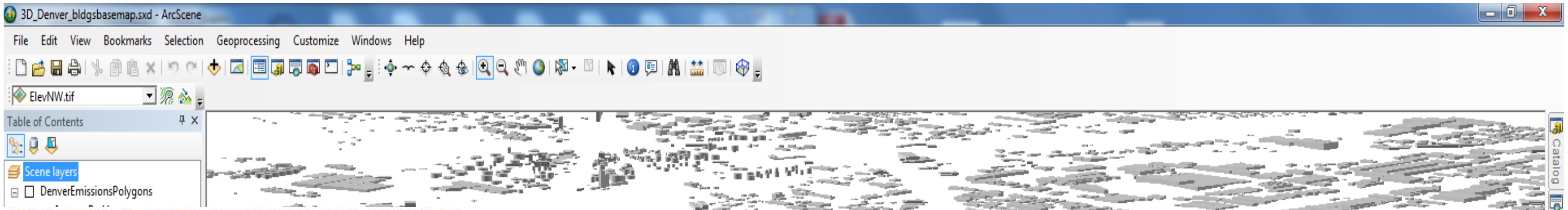
- The school proficiency index uses school-level data on the performance of 4th grade students on state exams to describe which neighborhoods have high-performing elementary schools nearby and which are near lower performing elementary schools. The school proficiency index is a function of the percent of 4th grade students proficient in reading (*r*) and math (*m*) on state test scores for up to three schools (i=1,2,3) within 1.5 miles of the block-group centroid.
- Elementary schools are linked with block-groups based on a geographic mapping of attendance area zones from School Attendance Boundary Information System (SABINS), where available, or within-district proximity matches of up to the three-closest schools within 1.5 miles. In cases with multiple school matches, an enrollment-weighted score is calculated following the equation above.
- ***Interpretation***
- Values are percentile ranked and range from 0 (worst-red) to 100 (best -green). The higher the score, the higher the school system quality is in a neighborhood.
- Data Source: Great Schools (proficiency data, 2011-12 or more recent); Common Core of Data (school addresses and enrollment, 2011-12); SABINS (attendance boundaries, 2011-12). Data is current as of 6/15/2015.

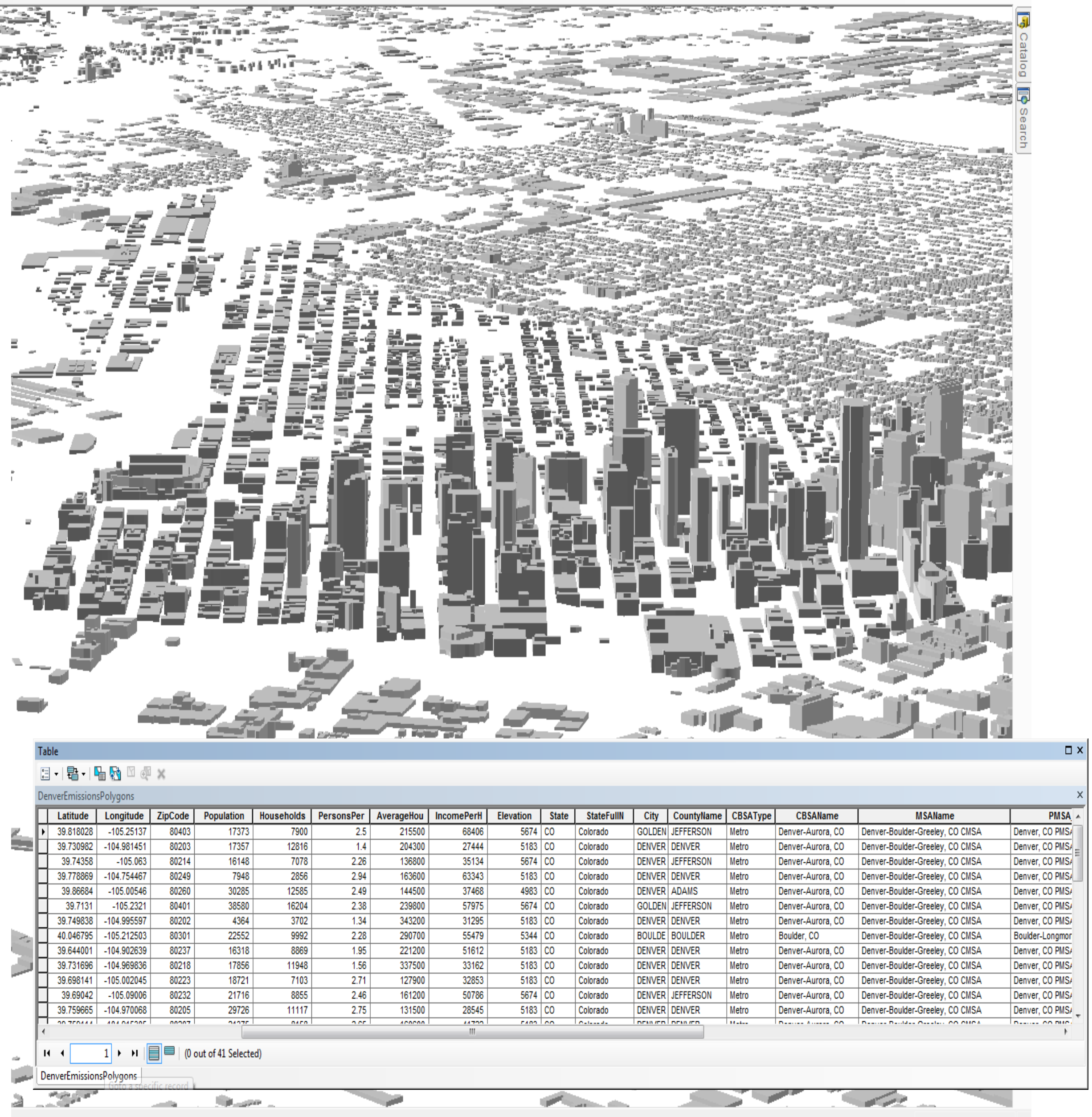
HUD Dataset – Location Affordability – Low Transportation Cost Index



Denver Metro Region, Colorado
Low Transportation Cost Index by Census Tract

- ***Summary***
- This index is based on estimates of transportation costs for a family that meets the following description: a 3-person single-parent family with income at 50% of the median income for renters for the region (i.e. CBSA). The estimates come from the Location Affordability Index (LAI). The data correspond to those for household type 6 (hh_type6_) as noted in the LAI data dictionary. More specifically, among this household type, we model transportation costs as a percent of income for renters (t_rent). Neighborhoods are defined as census tracts.
- ***Interpretation***
- Values are inverted and percentile ranked nationally, with values ranging from 0 (worst-red) to 100 (best-green). **The higher the transportation cost index, the lower the cost of transportation in that neighborhood. Transportation costs may be low for a range of reasons, including greater access to public transportation and the density of homes, services, and jobs in the neighborhood and surrounding community.**
- Data Source: Location Affordability Index (LAI) data, 2008-2012. Data is current as of 6/15/2015.





Latitude	Longitude	ZipCode	Population	Households	PersonsPer	AverageHou	IncomePerH	Elevation	State	StateFullN	City	CountyName	CBSAType	CBSAName	MSAName	PMSA
39.818028	-105.25137	80403	17373	7900	2.5	215500	68406	5674	CO	Colorado	GOLDEN	JEFFERSON	Metro	Denver-Aurora, CO	Denver-Boulder-Greeley, CO CMSA	Denver, CO PMSA
39.730982	-104.981451	80203	17357	12816	1.4	204300	27444	5183	CO	Colorado	DENVER	DENVER	Metro	Denver-Aurora, CO	Denver-Boulder-Greeley, CO CMSA	Denver, CO PMSA
39.74358	-105.063	80214	16148	7078	2.26	136800	35134	5674	CO	Colorado	DENVER	JEFFERSON	Metro	Denver-Aurora, CO	Denver-Boulder-Greeley, CO CMSA	Denver, CO PMSA
39.778869	-104.754467	80249	7948	2856	2.94	163600	63343	5183	CO	Colorado	DENVER	DENVER	Metro	Denver-Aurora, CO	Denver-Boulder-Greeley, CO CMSA	Denver, CO PMSA
39.86684	-105.00546	80260	30285	12585	2.49	144500	37468	4983	CO	Colorado	DENVER	ADAMS	Metro	Denver-Aurora, CO	Denver-Boulder-Greeley, CO CMSA	Denver, CO PMSA
39.7131	-105.2321	80401	38580	16204	2.38	239800	57975	5674	CO	Colorado	GOLDEN	JEFFERSON	Metro	Denver-Aurora, CO	Denver-Boulder-Greeley, CO CMSA	Denver, CO PMSA
39.749838	-104.995597	80202	4364	3702	1.34	343200	31295	5183	CO	Colorado	DENVER	DENVER	Metro	Denver-Aurora, CO	Denver-Boulder-Greeley, CO CMSA	Denver, CO PMSA
40.046795	-105.212503	80301	22552	9992	2.28	290700	55479	5344	CO	Colorado	BOULDE	BOULDER	Metro	Boulder, CO	Denver-Boulder-Greeley, CO CMSA	Boulder-Longmor
39.644001	-104.902639	80237	16318	8869	1.95	221200	51612	5183	CO	Colorado	DENVER	DENVER	Metro	Denver-Aurora, CO	Denver-Boulder-Greeley, CO CMSA	Denver, CO PMSA
39.731696	-104.969836	80218	17856	11948	1.56	337500	33162	5183	CO	Colorado	DENVER	DENVER	Metro	Denver-Aurora, CO	Denver-Boulder-Greeley, CO CMSA	Denver, CO PMSA
39.698141	-105.002045	80223	18721	7103	2.71	127900	32853	5183	CO	Colorado	DENVER	DENVER	Metro	Denver-Aurora, CO	Denver-Boulder-Greeley, CO CMSA	Denver, CO PMSA
39.69042	-105.09006	80232	21716	8855	2.46	161200	50786	5674	CO	Colorado	DENVER	JEFFERSON	Metro	Denver-Aurora, CO	Denver-Boulder-Greeley, CO CMSA	Denver, CO PMSA
39.759665	-104.970068	80205	29726	11117	2.75	131500	28545	5183	CO	Colorado	DENVER	DENVER	Metro	Denver-Aurora, CO	Denver-Boulder-Greeley, CO CMSA	Denver, CO PMSA

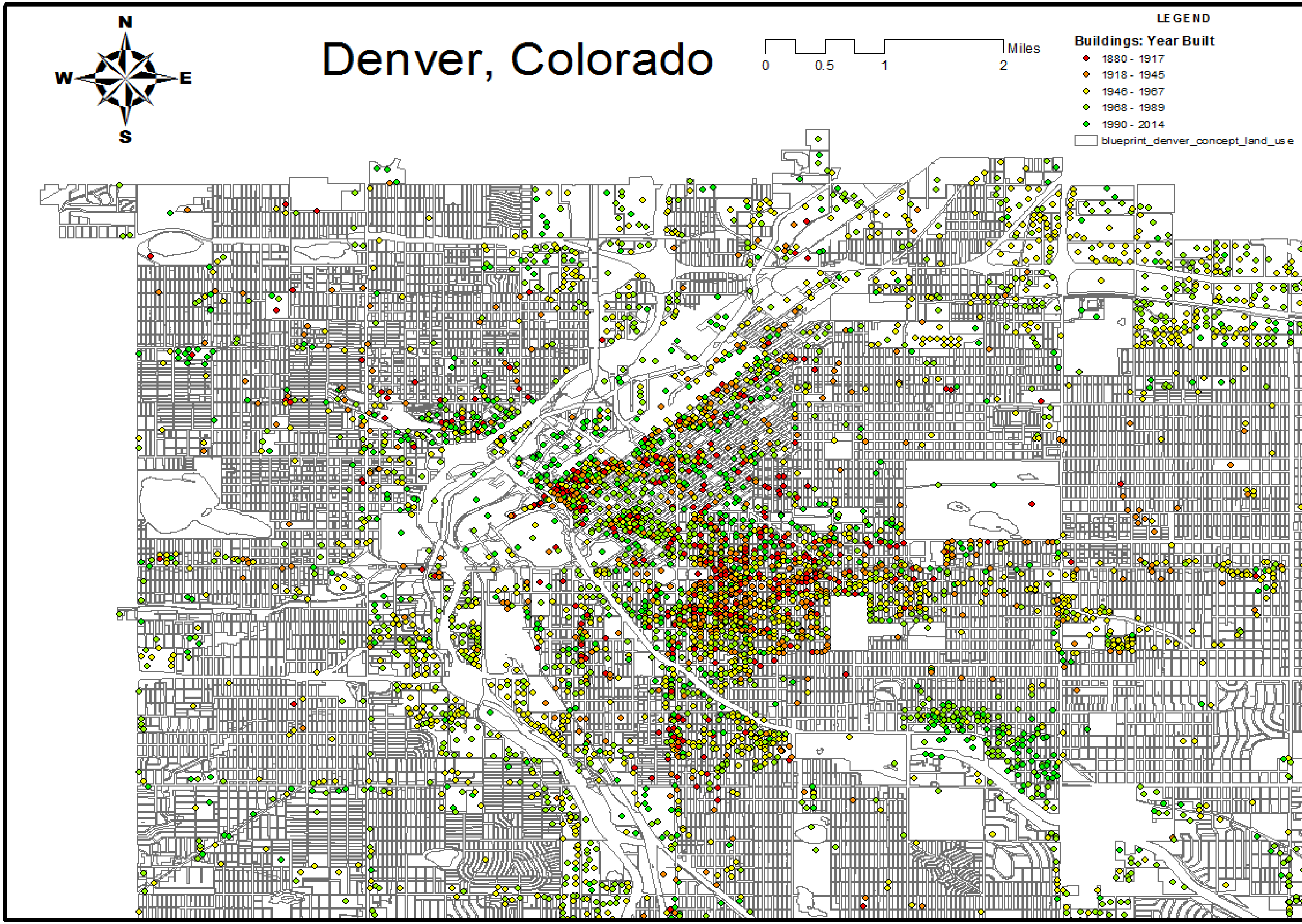
Sustainability in the Downtown DC ecoDistrict

Autodesk's InfraWorks 360 generated a model of the Downtown ecoDistrict that was used to:

- Detect which buildings are ready for retrofit and which systems to upgrade, using Rapid Energy Modeling
- Model green infrastructure at the site scale to calculate stormwater retention credits, and at the district scale to retain 100% stormwater, using Green Stormwater Infrastructure
- Calculate triple bottom line benefits of the National Mall Underground project, using AutoCASE

You can read the full case study here: **Sustainable Strategies for Energy and Stormwater Management**

How does your city measure up?



N
W
E
S
Denver, Colorado
Miles
0
0.5
1
2
LEGEND
Buildings: Year Built
1880 - 1917
1918 - 1945
1946 - 1967
1968 - 1989
1990 - 2014
blueprint_denver_concept_land_use