Gigaton Problems Require Gigaton Solutions: Urban Systems and Technology Opportunities

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Core Team Members - I would like to express my thanks to the following colleagues for their contributions to this presentation:

- Steve French
- Ming Xu
- Ke Li
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- Douglass Noonan
- Valerie Thomas
- Bert Bras
- Miroslav Begovic

Outline

- What is Sustainability ?
- What is the Gigaton Problem?
- Urban Development Simulation, Infrastructure Ecology
- Material Flow Analysis
- Air Quality, Heat Island, Noise, Carbon Foot Print Simulations
- Conclusions

Sustainable Urban Systems

- We need to recreate the anthrosphere to exist within the means of nature. That is, use resources that nature provides and generate waste nature can assimilate without overwhelming natural cycles.
- This will require us to examine the interactions between the engineered, social and economic systems.

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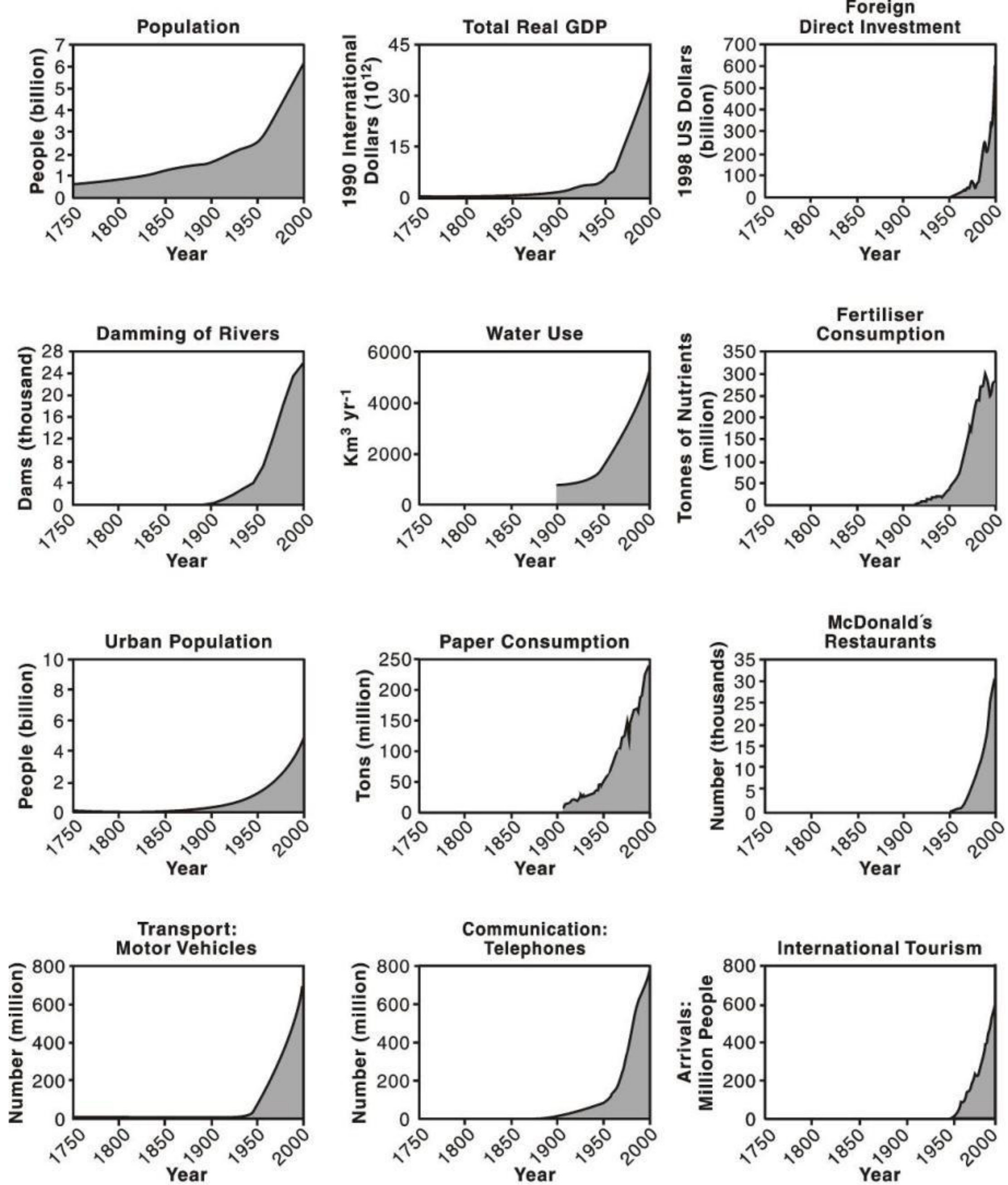
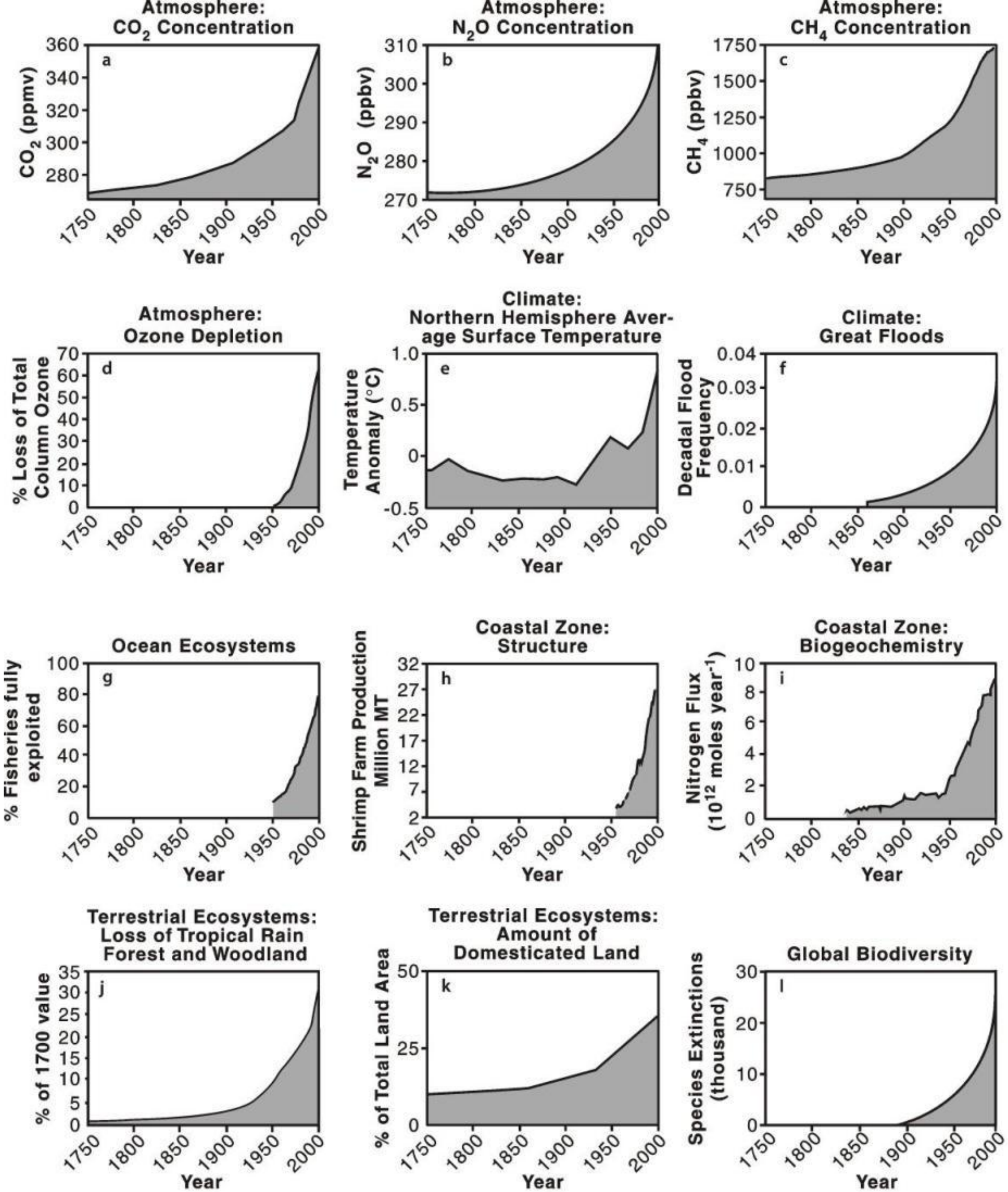
Great Acceleration: Increasing Human Activities



- Steffen, W.; Sanderson, A.; Tyson, P. D., et al. *Global Change and the Earth Systems: A Planet Under Pressure*; Springer-Verlag: Heidelberg, Germany, 2005

Environmental and Ecological Consequences (Could be 9 times worse)



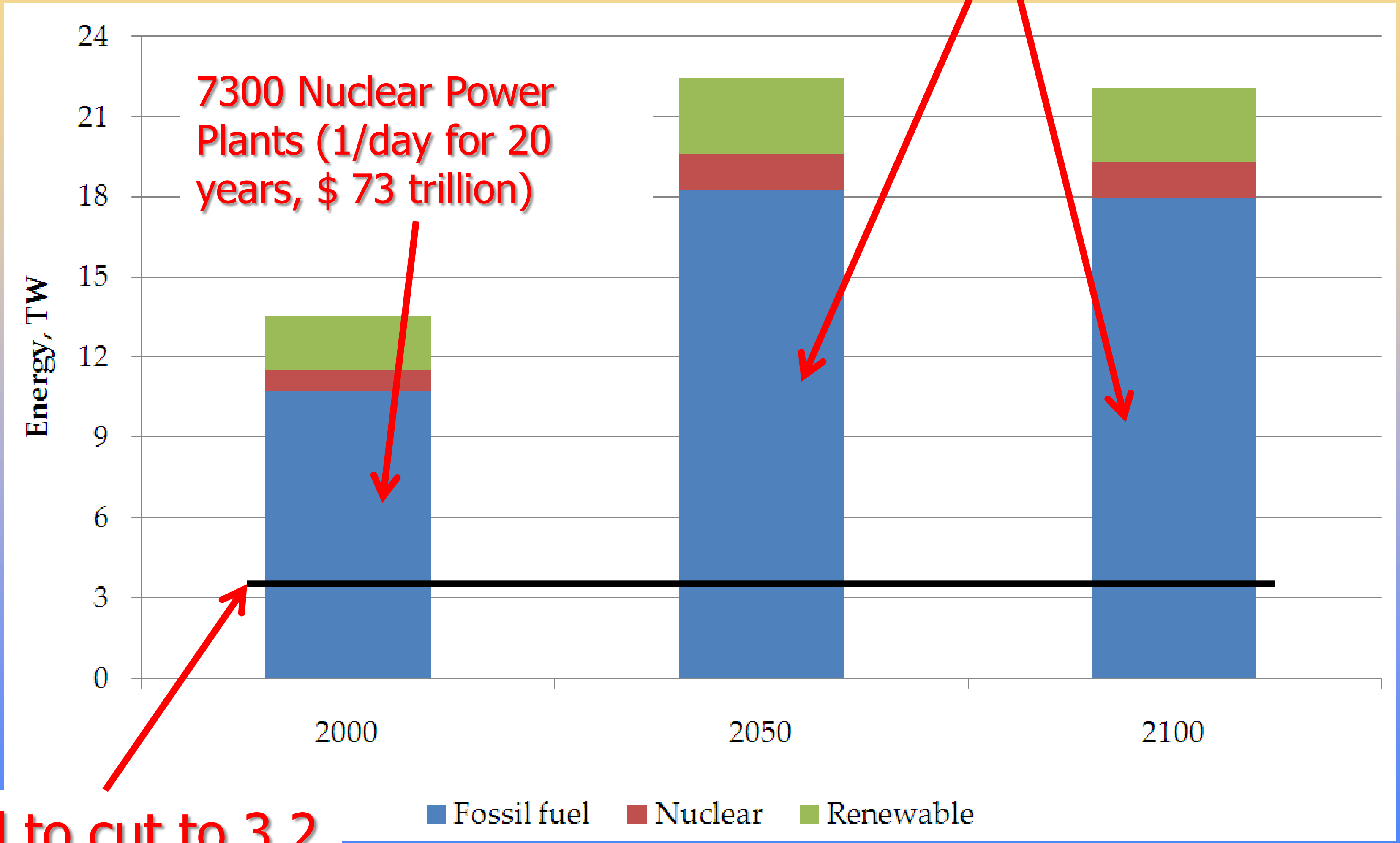
- Steffen, W.; Sanderson, A.; Tyson, P. D., et al. *Global Change and the Earth Systems: A Planet Under Pressure*; Springer-Verlag: Heidelberg, Germany, 2005

CO_2 Target – 70% Reduction by 2100, 30% by 2050

NCAR study published in *Geophysical Research Letters(2009)*

- Supercomputer studies with the NCAR-based Community Climate System Model (CCSM)
- Negative effects of climate change are unavoidable, but…
- If CO2 stabilized at 450 ppm, worst effects could be avoided.
- Sea-level rise would be about 14 cm (thermal expansion).
- Permafrost and Land Based Glacier Melt would largely be avoided.
- Business-as-usual = 750 ppm by 2100

Not Meant as Nuclear Power - Bashing but Nuclear Option = 16,300 Plants (Build 1/day for 44 years, $163 trillion)



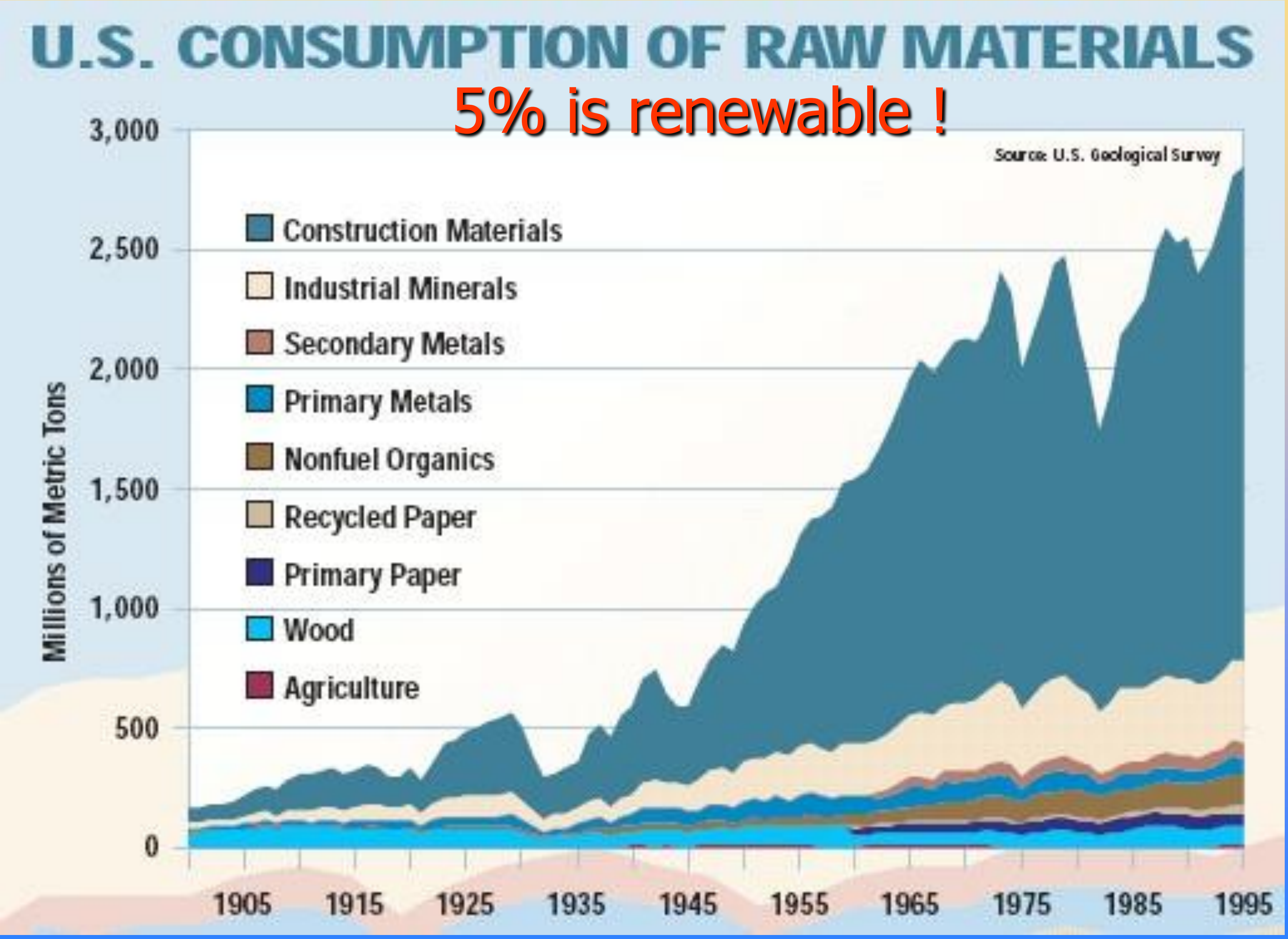
Need to cut to 3.2 TW to Achieve 70% Reduction

WWIII - The Plan

- To power the world with 11.5 TW WWS energy
  - 51% by wind (5.8 TW)
    - 3.8 million large wind turbines (5 MW each), 0.8% in place
  - 40% by solar (4.6 TW)
    - 1.7 billion rooftop PV systems (0.003 MW each), <1% in place
    - 89,000 PV and concentrated solar power plants (300 MW each)
  - 9% by water (1.1 TW)
    - 900 hydroelectric plants (1,300 MW each), 70% in place

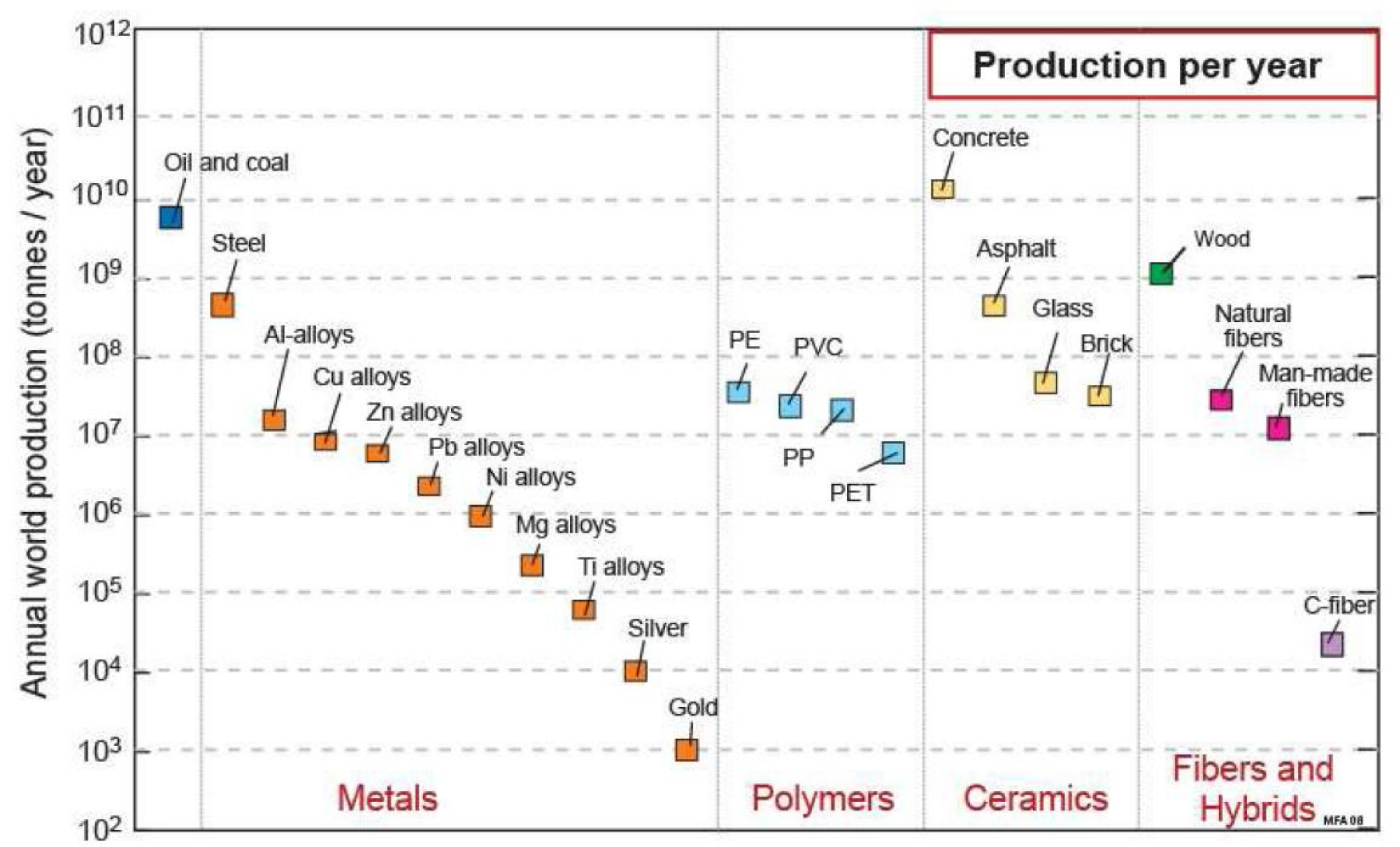
Jacobson and Delucchi, 2009

Importance of Construction



(USGS, 2000)

Resource Consumption for Material Production



Credit: Mike Ashby

Iron Intensity for Transportation Options (180 persons)

Transport Technologies and Iron Intensity

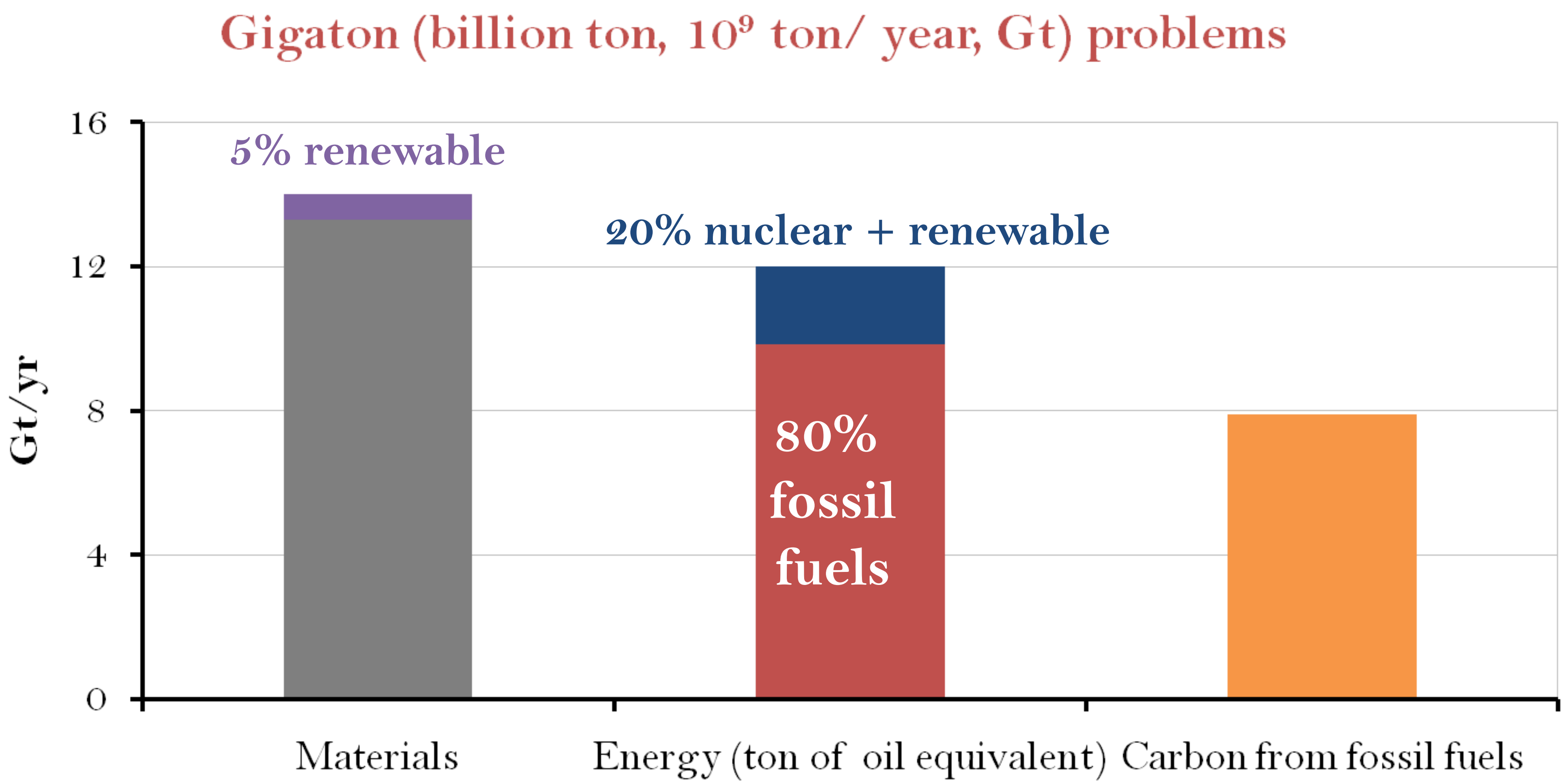
- No iron

- 10 Mg Fe/bus
- 170 kg Fe/cap

- 1 Mg Fe/car
- 670 kg Fe/cap

Bicycles 15 kg/cap

Gigaton problems Require Gigaton Solutions!



Fundamental Question for Solving the Gigaton Problems

Which will give the biggest payoff for the same investment of resources?

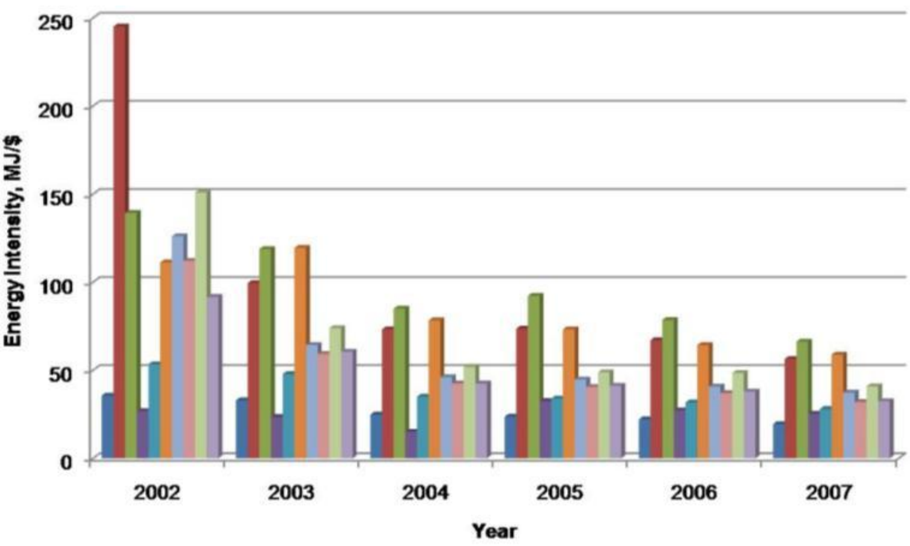
Energy

1. Develop greener energy production systems.
2. Implementing existing renewable energy technologies.

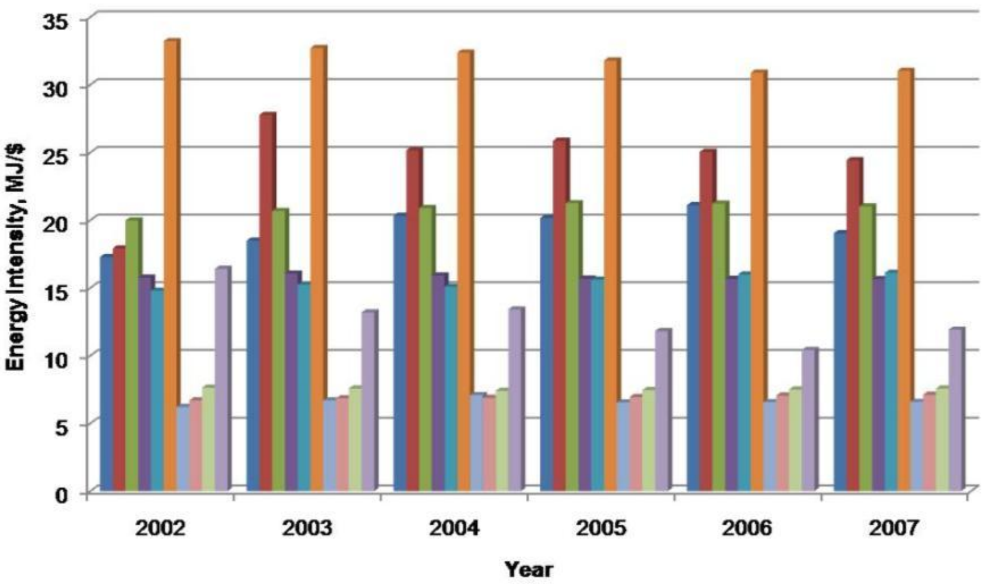
Materials

1. Refine existing technologies to use less energy and materials. For example, can we improve concrete, plastic, steel, aluminum, glass, etc. production to reduce energy use and reduce material use. Can we use less?
2. Develop new (green field) technologies that use renewable materials and less energy for production.

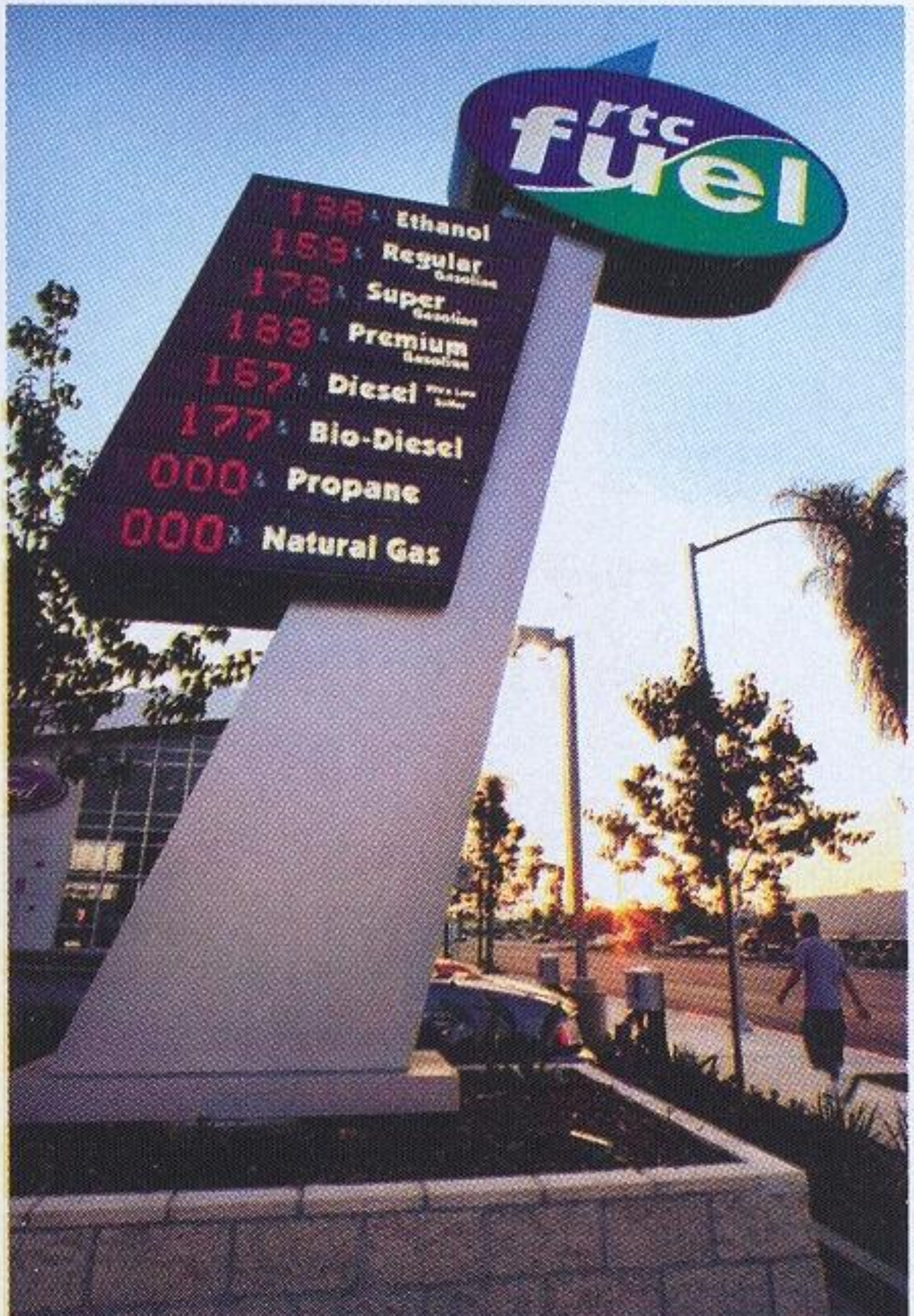
Energy Intensity (MJ/$) - Includes Purchasing Price Parodity



China



U.S.



Pick your mix

There is no single answer. Conservation can play a role!

Cost of energy savings is 1.8 cent/Kwhr

Cost of providing new energy production is 10.5 cents/Kwhr

Gigaton problems need gigaton solutions

- A substantial fraction of the gigaton problems derives directly from the structure and operation of urban infrastructures
- Create market incentives or stipulate mandates that get gigaton-investors and gigaton-entrepreneurs on task

- There are over 76 million residential and 5 million commercial buildings in the U.S.
- Commercial and residential building construction constitutes $805 billion of our GDP (6.1% of $13.2 trillion).
- According to the US Green Building Council/EPA, in the United States, buildings account for:
  - 72% of electricity consumption,
  - 39% of energy use,
  - 38% of all carbon dioxide (CO_2) emissions,
  - 40% of raw materials use,
  - 30% of waste output (136 million tons annually),
  - 14% of potable water consumption.

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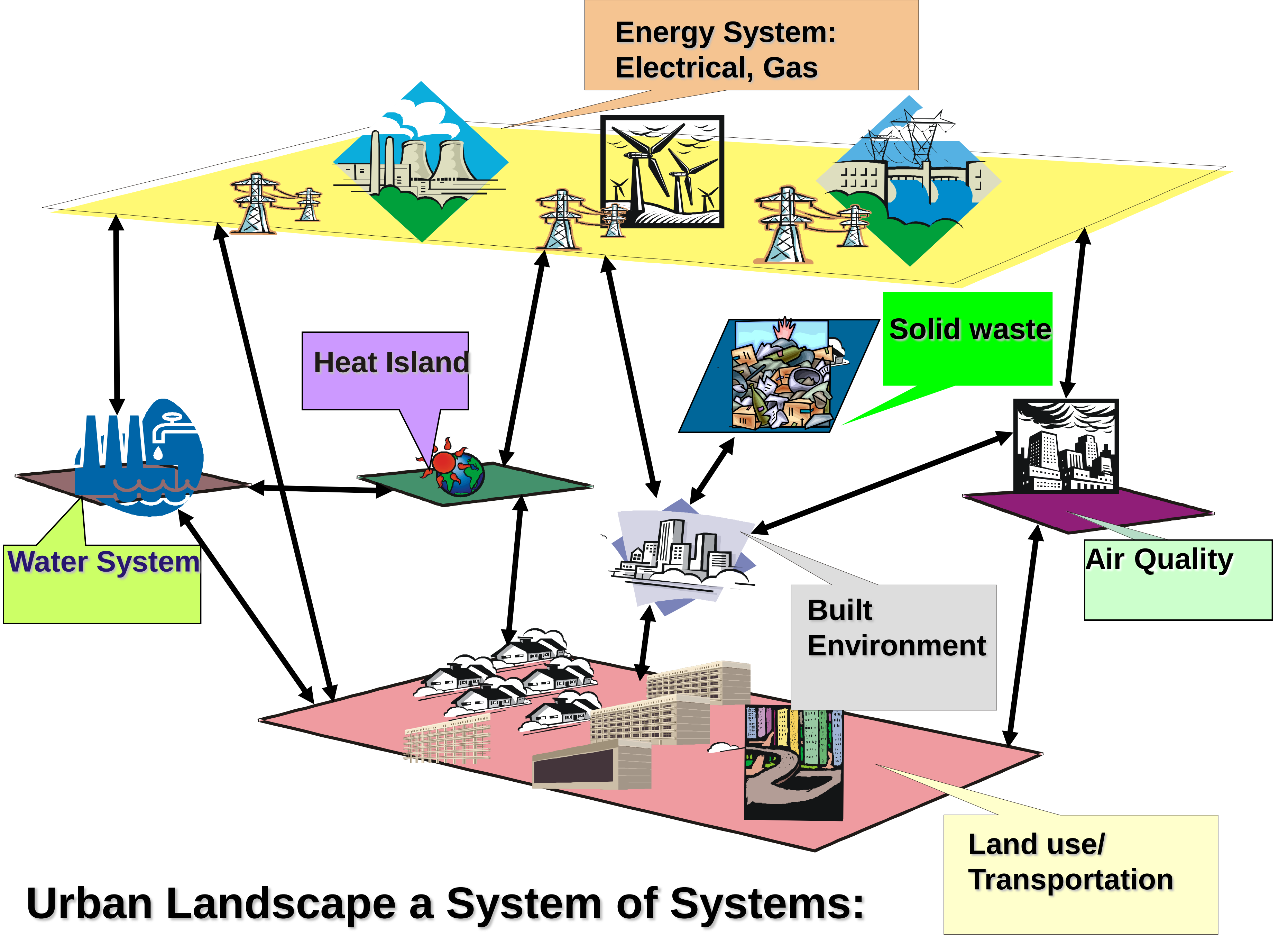
Urban Transformation

- **Double the urban infrastructure in the next 35 years (Took 5,000 years to get to this point)**
- **Challenge will be to be to insure that we develop long terms social, economic and environmental assets and not liabilities.**
- **It will last more that 50 years and 80 to 90% of the impact is during the use phase.**
- **Currently 49% of the world's population and 81% of the US population lives in urban areas, a figure which is expected to grow to 61% and 87%, respectively, 2030 (UNEP, 2005)**



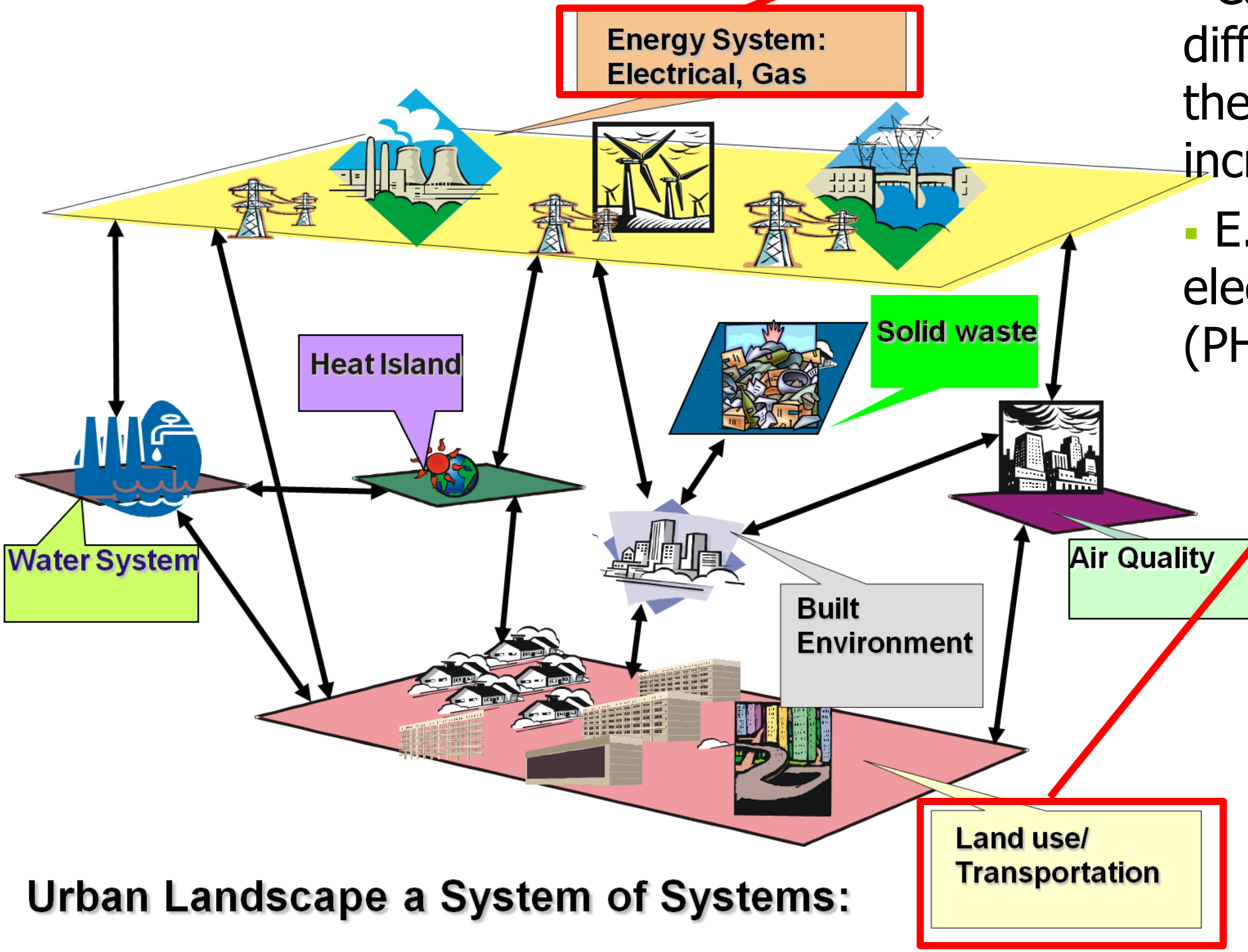
Urban Landscape a System of Systems:

Infrastructure ecology

- Reorganizing the linkage among individual infrastructure systems is like changing food chains in ecology. The analogy is infrastructures are species and the urban system is an ecosystem.
- This **infrastructure ecology** has a high potential to significantly contribute to solving the gigaton problems.
- The engineering community needs to lead in studies of **infrastructure ecology** and solutions to the gigaton problems through the development of integrated and efficient infrastructure.

Reorganizing the infrastructure ecology

- Waste heat from electricity production could be utilized as heat through use of district heating systems or through application to food production systems or industrial processes
  - In the U.S., combined heat and power could potentially provide 20% of U.S. electricity by 2030, reducing CO_2 emissions by 0.8 gigatons annually
- Use of biomass to produce combined heat and power is more efficient than use of biomass to provide electricity or heat alone
- Recovery and reuse of nutrients from urban wastewater can contribute to reducing long-term water contamination problems and can simultaneously reduce water consumption
- Linking transportation and energy systems via instruments like a gas tax suggest that an "optimal" gas tax in the U.S. alone would reduce gasoline consumption by roughly 13%.
- Linking land use and built environment, water, and energy systems via a policy tool like impact fees (or land use regulations) can also encourage the innovation and adoption of more sustainable technologies and systems



Urban Landscape a System of Systems:

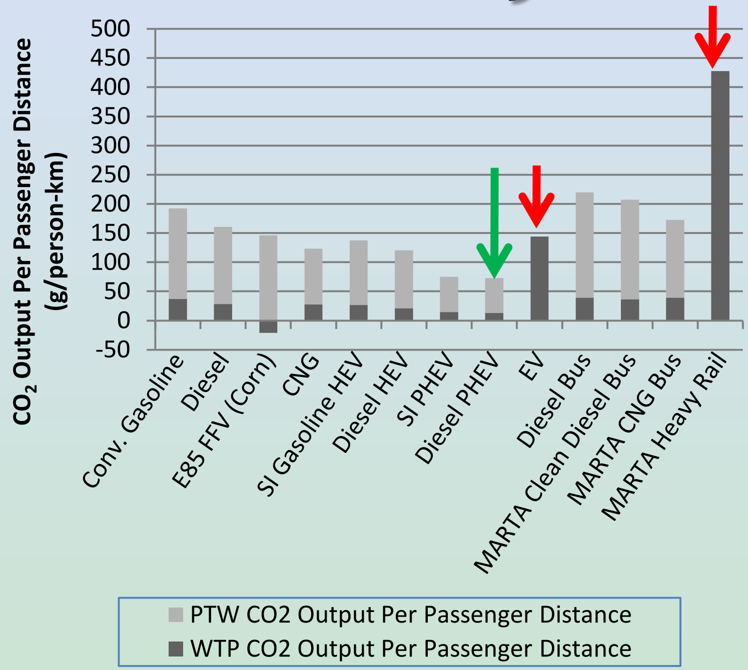
- Two of the largest components of the urban system
- Can make big difference by combining them together to increase efficiencies
- E.g., plug-in hybrid electric vehicles (PHEVs)

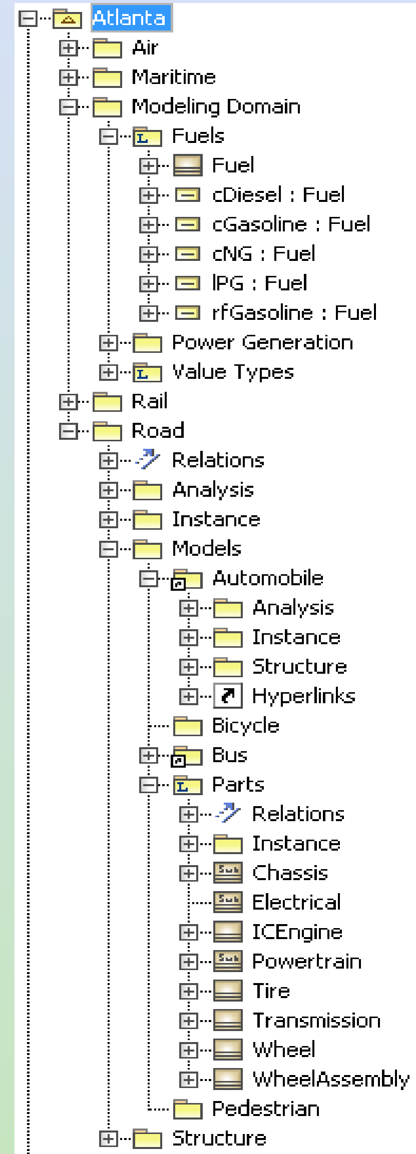
Plug-in Hybrid Electric Vehicles (PHEVs)

- ❑ 73% of the U.S. light duty vehicle fleet (cars, pickup trucks, SUVs, and vans) can be supported by existing electric power infrastructure
  - ✓ 43% if only charging vehicles between 6pm-6am
- ❑ This is equivalent to 52% of the nation's oil imports (we import 50% of our oil)
- ❑ 27% of total greenhouse gas emissions can be reduced even if we use coal fired power plants
  - ✓ Key driver: overall improvement in efficiency of electricity generation compared to the conversion process from crude oil to gasoline to the combustion in the vehicle
- ❑ Utility cost (life-cycle) can be reduced between 7%~26%

Credit: PNNL 2007

Atlanta: Preliminary Results





ATL SysML Model

- Poor environmental performance of electric vehicles, all sizes, due to coal fired powerplants
  - Georgia Power's Plant Bowen emits about 0.9kgCO_2/kWh and consumes (evaporates) about 0.4 gallons H2O/kWh
- Marta rail & bus performance bad due to low ridership

Azevedo, K., Doshi, S., Bras, B., and Guldberg, T., "Modeling Sustainability of Complex Systems: A Multi-Scale Framework using SysML", Paper no. DETC2009/87496, 2009 International Design Engineering Technical Conferences and Design for Manufacturing and the Life Cycle Conference, San Diego, CA, Aug. 30-Sept 2, 2009

In progress: Addition of water assessments

Brook Byers Institute for Sustainable Systems

Bert Bras

Georgia Institute of Technology

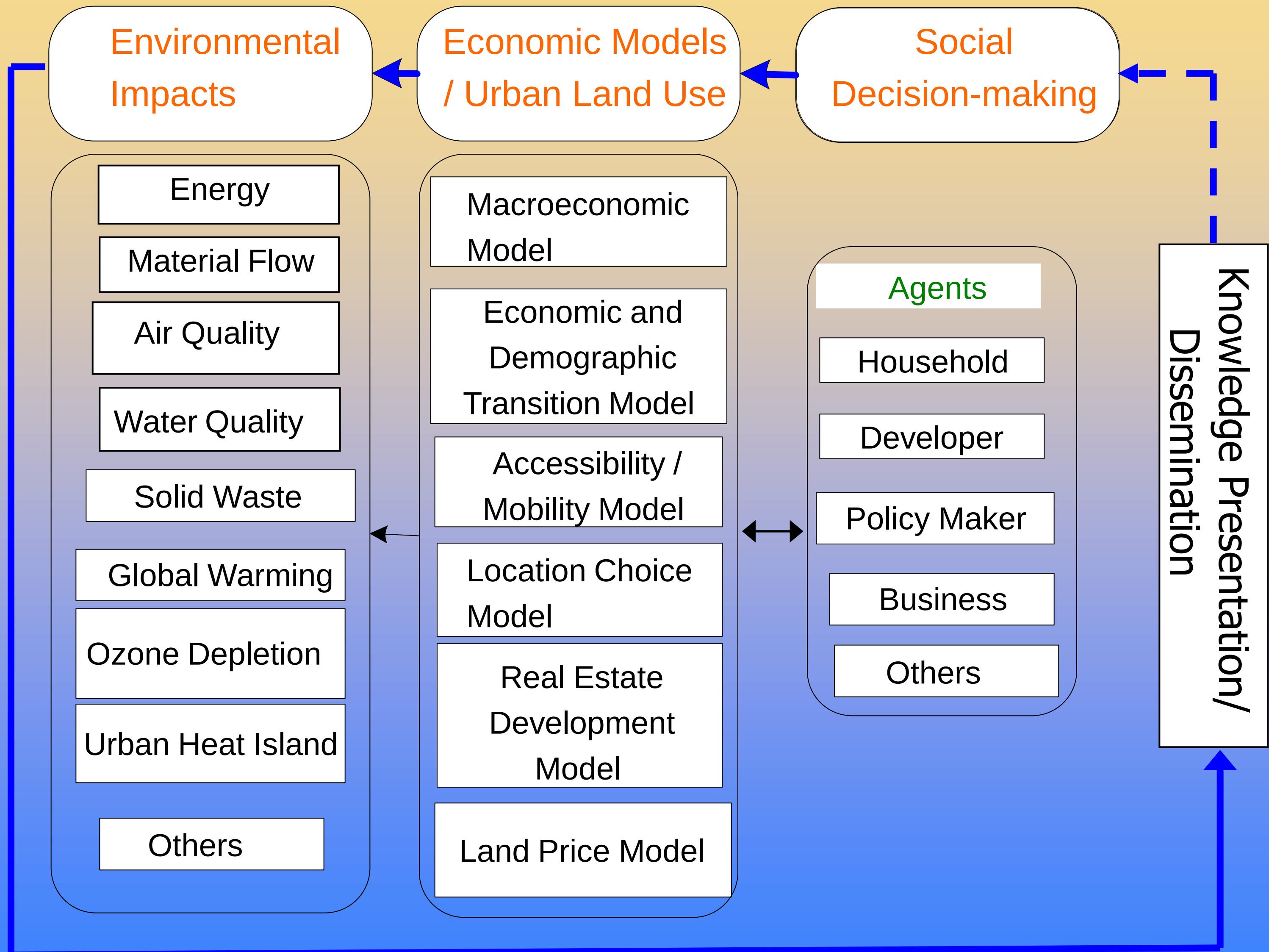
System Combinations Land Use, Water Use, Transportation, Economic Flows

- Land Use
- Distributed Energy and Water Production
- Transportation
- Urban Form and Planning
- Real estate and other tax revenues
- Separate storm water treatment systems – Vancover turning 4 billion dollar expense into a 400 million dollar advantage

Sustainable Urban Systems - Our Goals

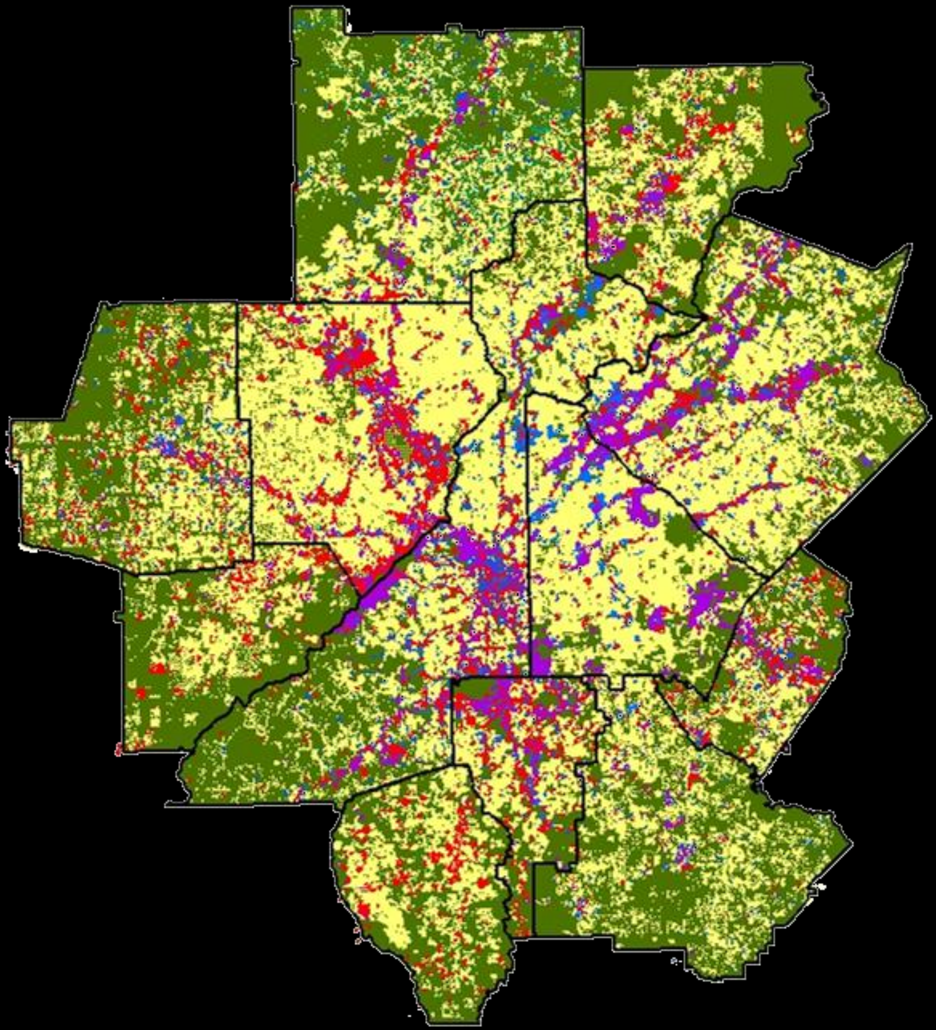
- Predict the emergent properties of urban systems (e.g., economic structures, material, energy use, traffic and transportation patterns, urban health, heat island, land use and density, air quality, local regional and global impacts of the resource demands and waste generation)
- Understand how the flows of resources (information, energy, and materials) are utilized within the urban system of systems (Urban Metabolism) and reduce material and energy investments
- Develop the cyber infrastructure to gather information monitor, model and visualize the complex emergent properties
- Develop the pedagogy of engineering complex systems in the context of sustainability of urban systems

Framework of agent based models

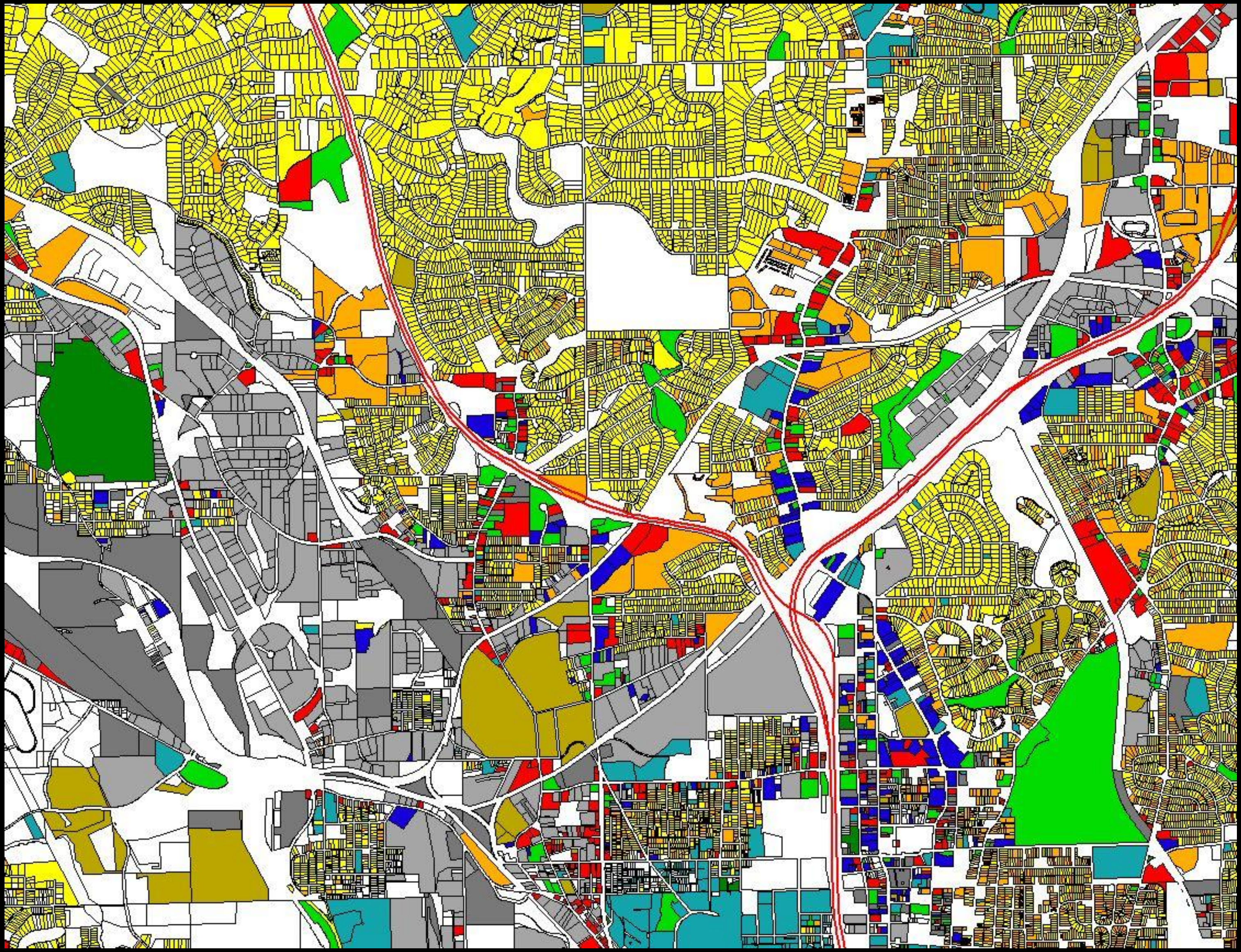


■Spatial Databases for Urban Modeling - 1

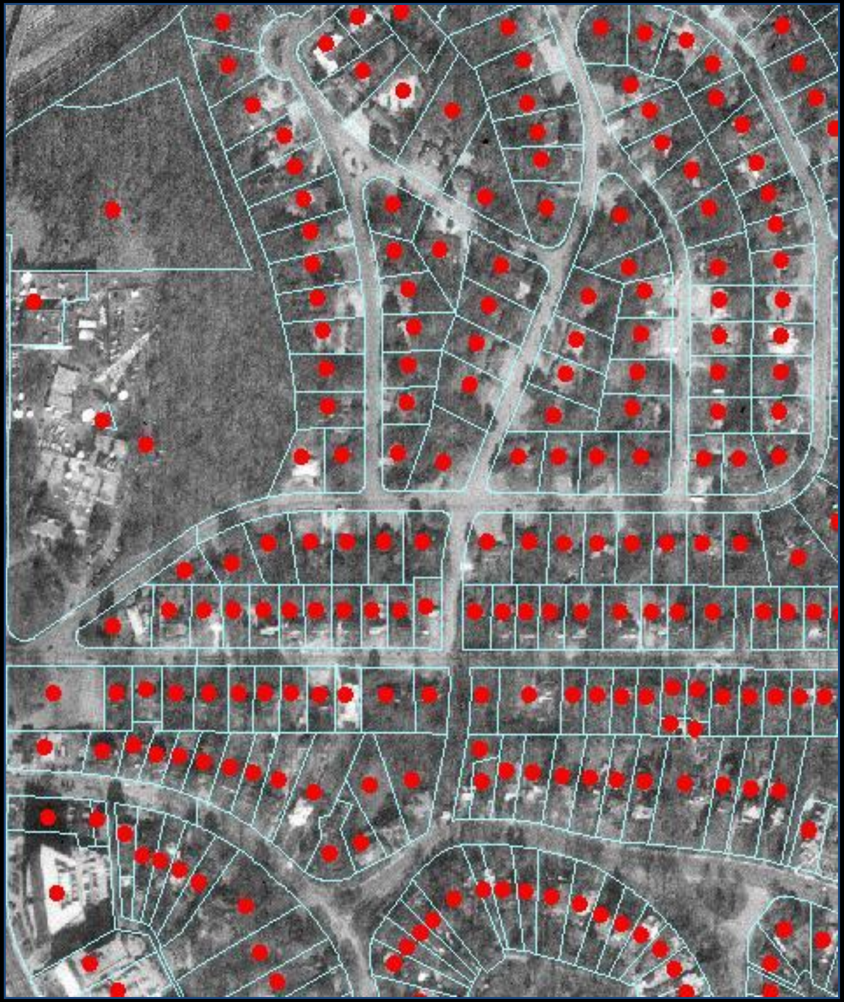
- The SMARTRAQ project
  - Supports research on land use impact on transportation and air quality
  - 1.3 million parcels in the 13 metropolitan Atlanta non-attainment counties



■Parcel-based Spatial Data



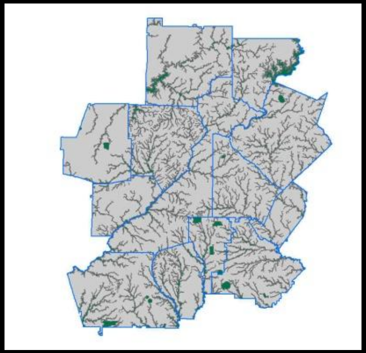
SMARTRAQ DATA AND ATTRIBUTES



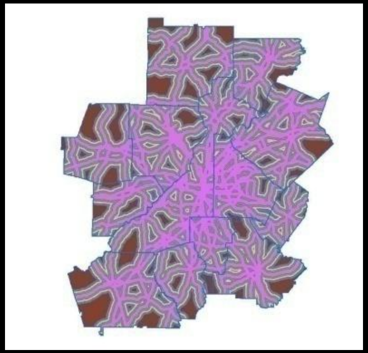
- Address
- Road Type
- City
- Zip Code
- Owner Occupied
- Commercial/Residential
- Zoning
- Sale Price
- Sale Date
- Tax Value
- Assessed Value
- Improvement Value
- Land Value
- Year Built
- No. of Stories
- Bedrooms
- Parking
- Acreage

- **Residential Units**
- **X,Y Coordinate**
- **Estimated Sq Feet**
- **Total Sq Feet**

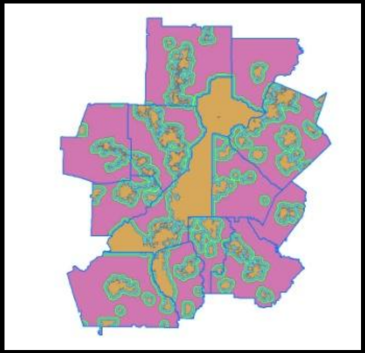
Important Features



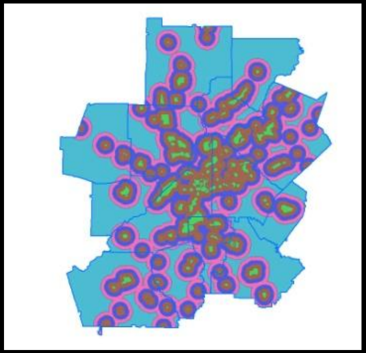
Floodplain



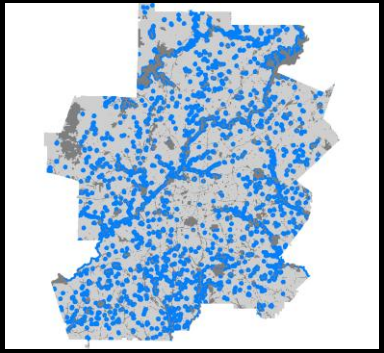
Highway Buffers



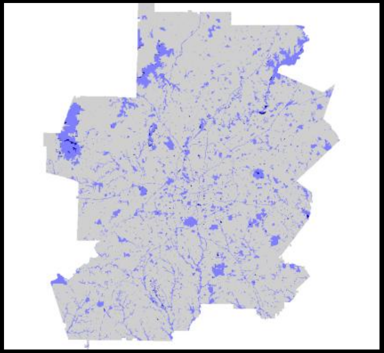
Sewer Service



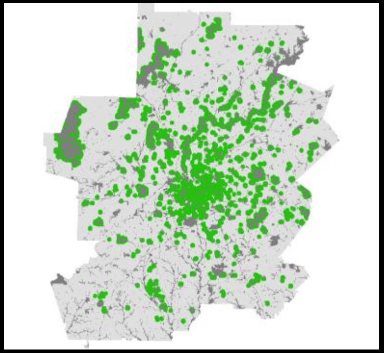
Employment Centers



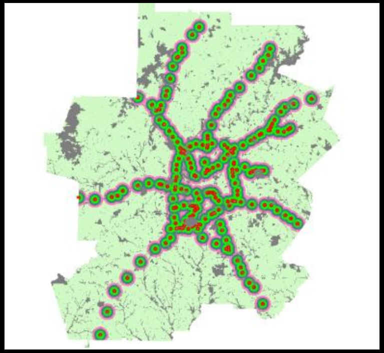
Lake Buffers



Public lands



Parks



Ramp Buffers

WHAT IF – Scenarios and Results

Land use and Employees per acre were predicted based on the input datasets, weight, and rating.

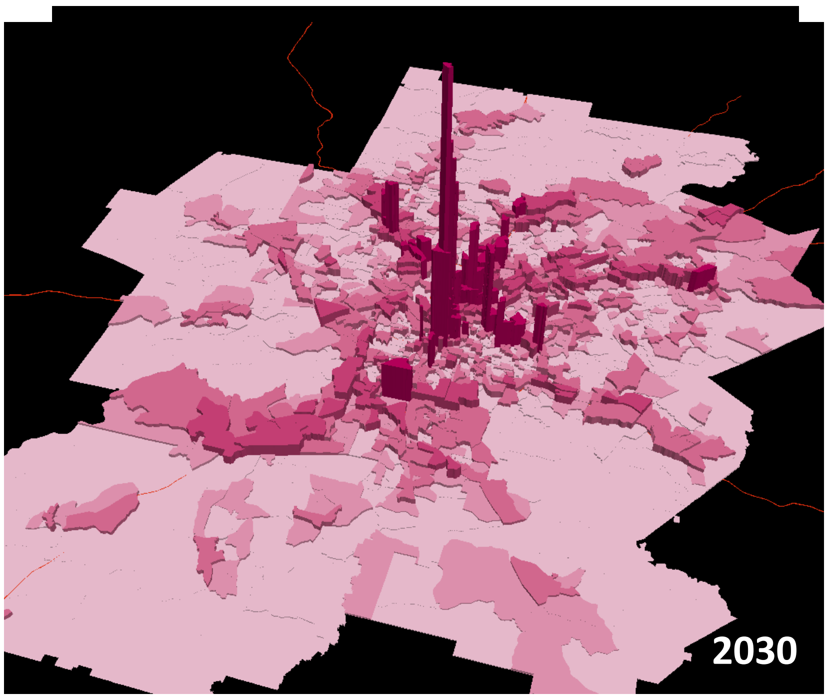
Land Use

- Residential
- Employment
- Open Water
- Undeveloped
- Wetlands
- Undevelopable

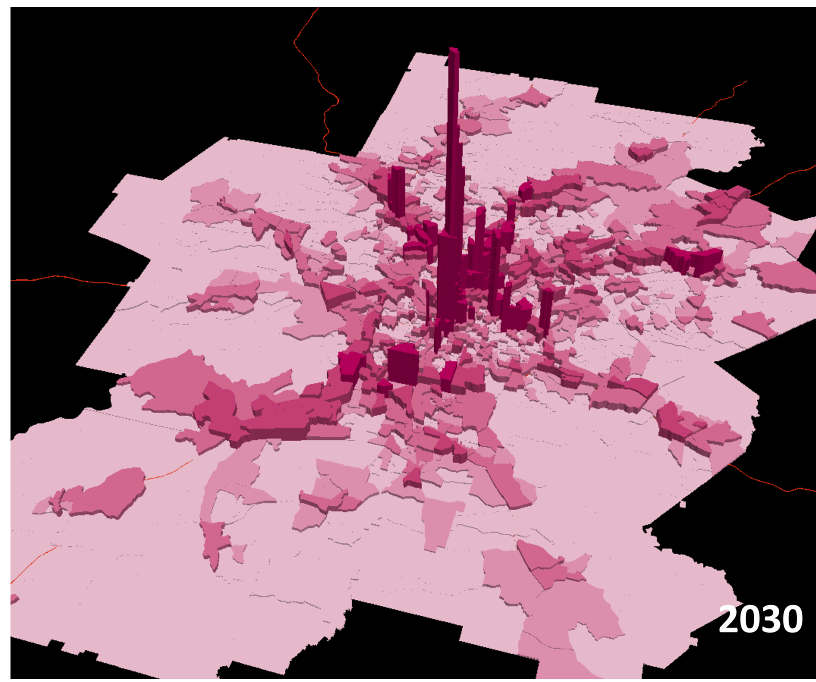
Employees /Acre

- 0.0 - 1.000
- 1.001 - 2.000
- 2.001 - 5.000
- 5.001 - 10.00
- 10.01 - 200.0

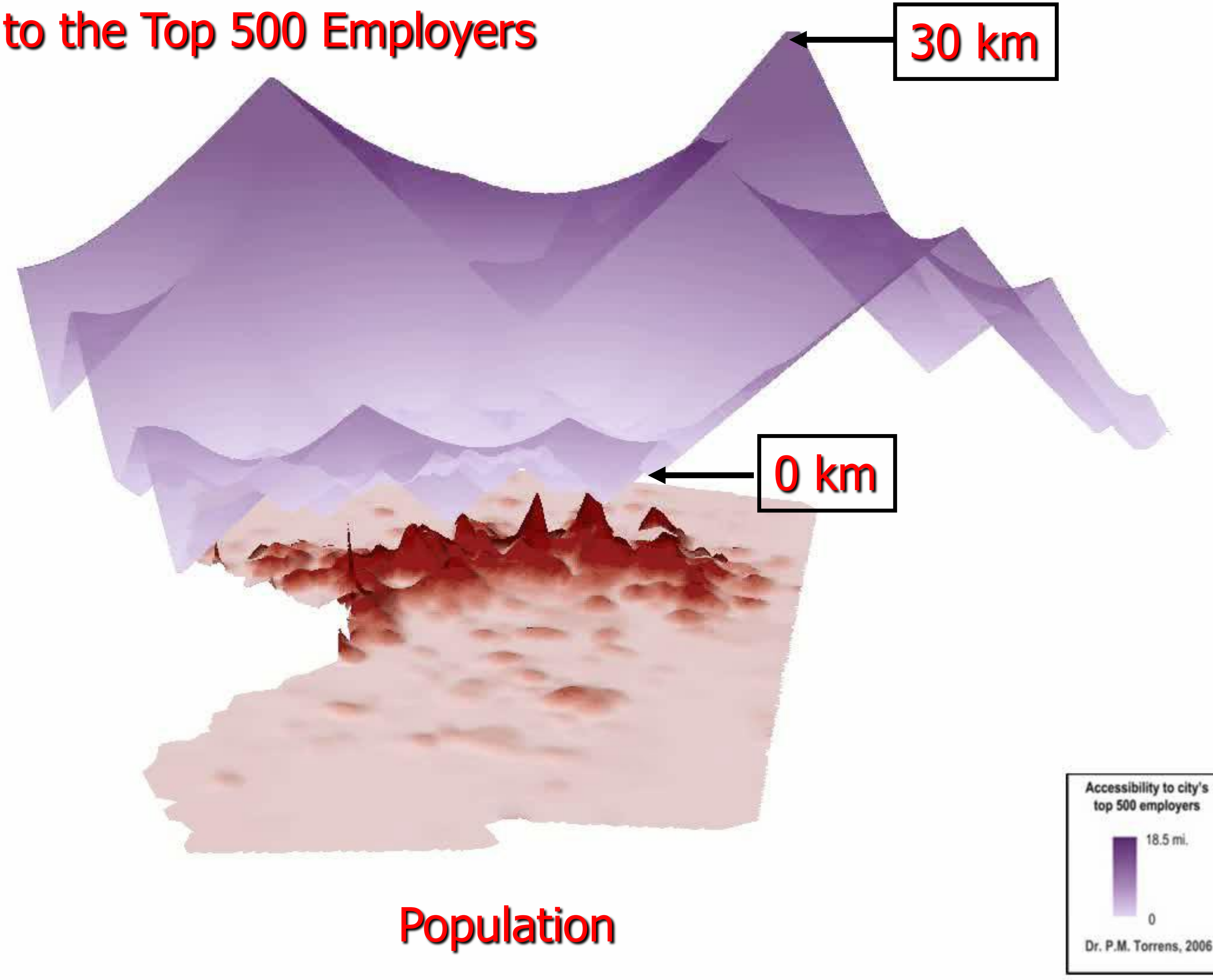
Scenario 1. Business as Usual



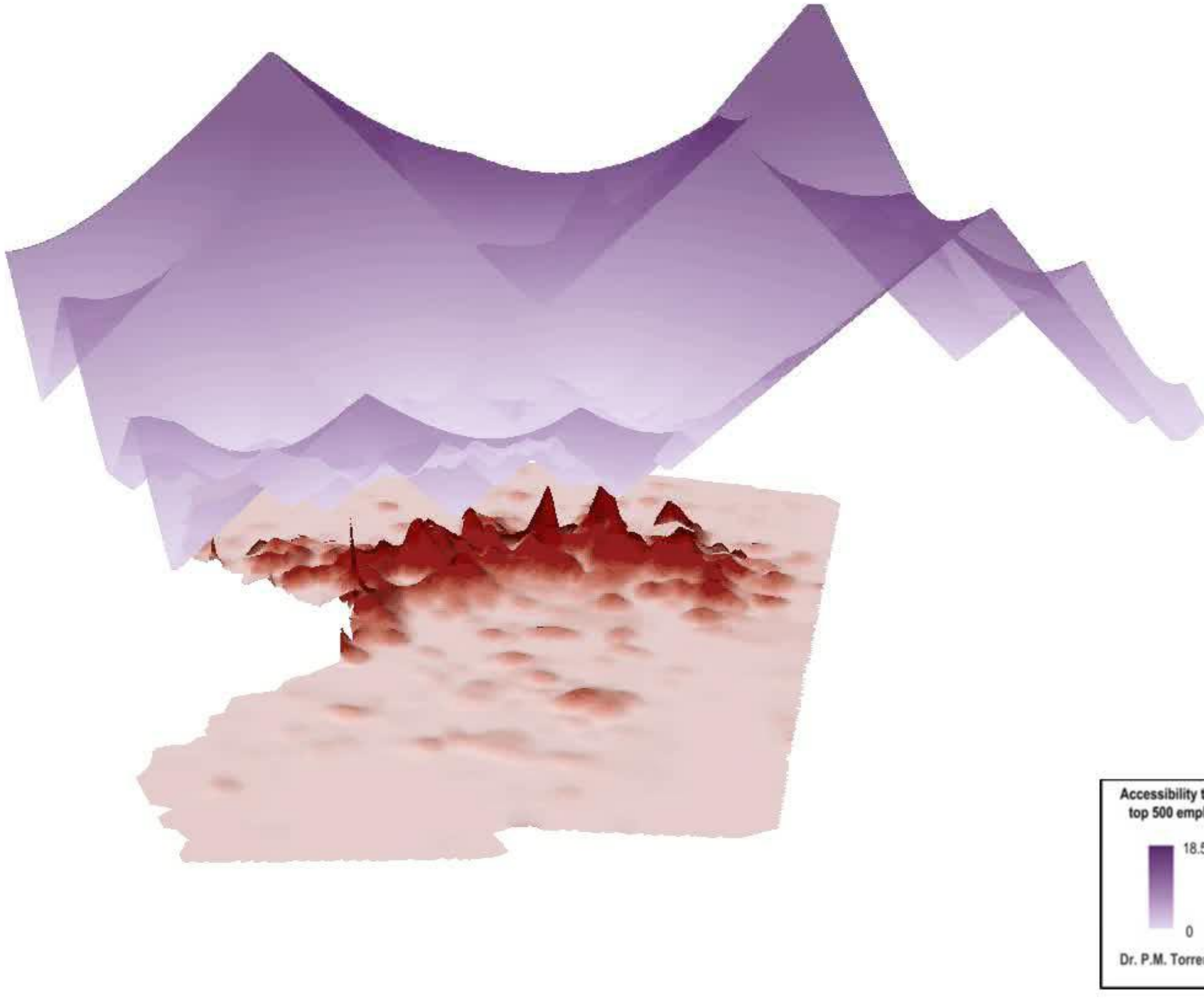
Scenario 2. Compact Growth



Access to the Top 500 Employers



Population



movie-measuring-sprawl-access-to-top500-employers

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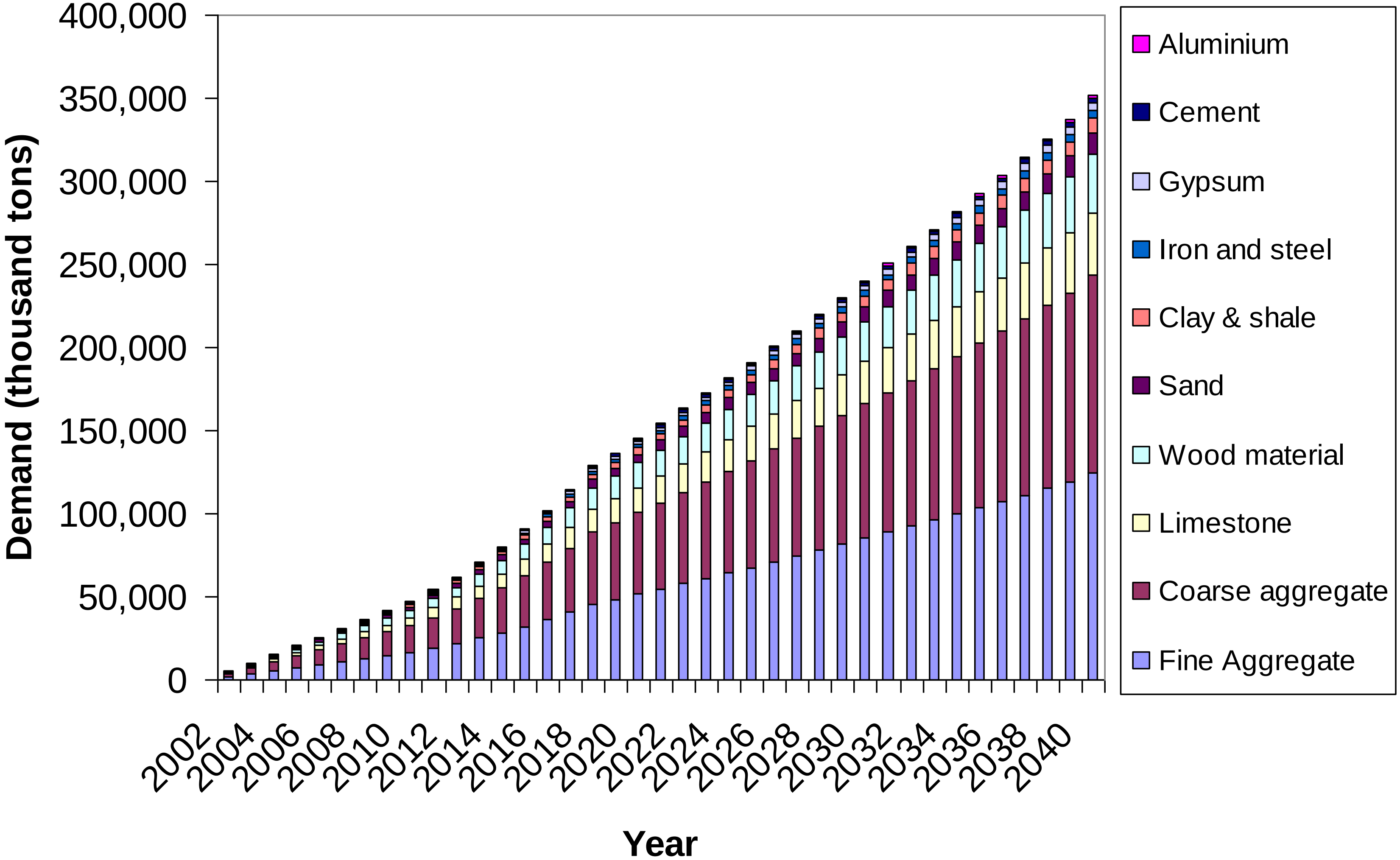
Cumulative Residential Construction Material Demands From 2002 to 2040 – Business as Usual for Phoenix



Future Work - Land and Material Use Scenarios, e.g., for Development

- Three General Plan Scenarios (slow growth, General Plan growth, fast growth)
- Dispersed Polynucleated City
- Strong Central City
- Resort Mecca
- Transportation Influenced

Importation: Scottsdale

- **Receives water from Central Arizona Project (CAP Plant)**
  - **200 mile canal**
  - **Conventional water treatment processes**
  - **Portion of the impacts based on portion of total water received (3%)**

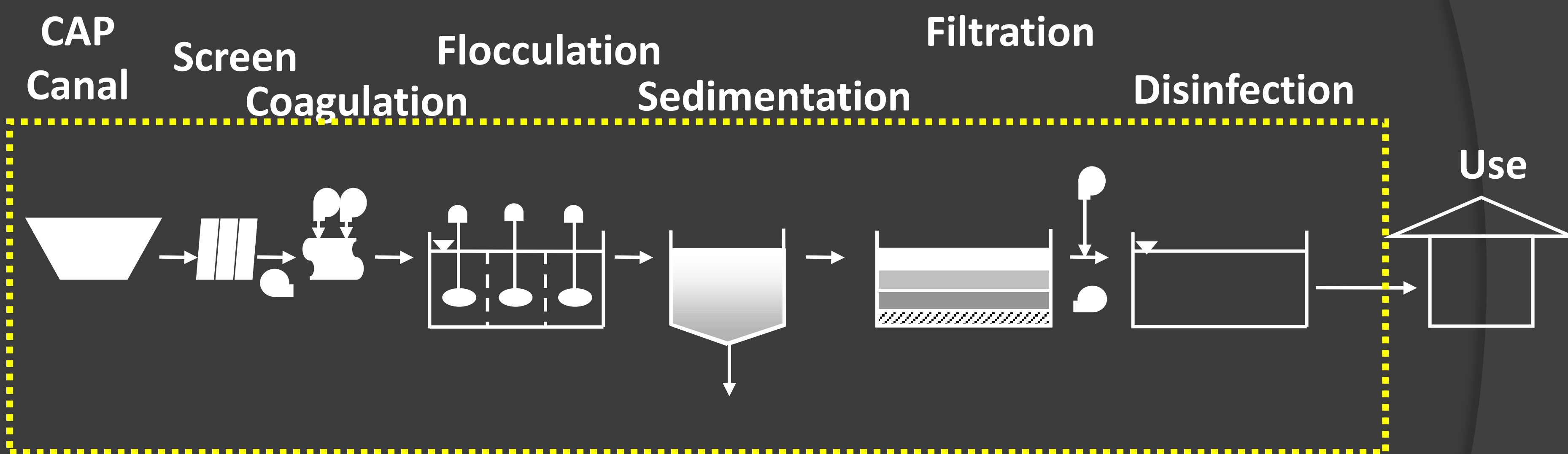
Desalination: Scottsdale

- Seawater is desalinated at the Sea of Cortez and then transported to Phoenix
  - Desalination plant at the Sea of Cortez
  - Pipeline system for water transportation (165 miles)

Reclamation: Scottsdale

- Reclaims wastewater for use (Reclaimed Plant)
  - Wastewater treatment, advanced water treatment, and groundwater recharge and extraction
  - Supplemented by groundwater

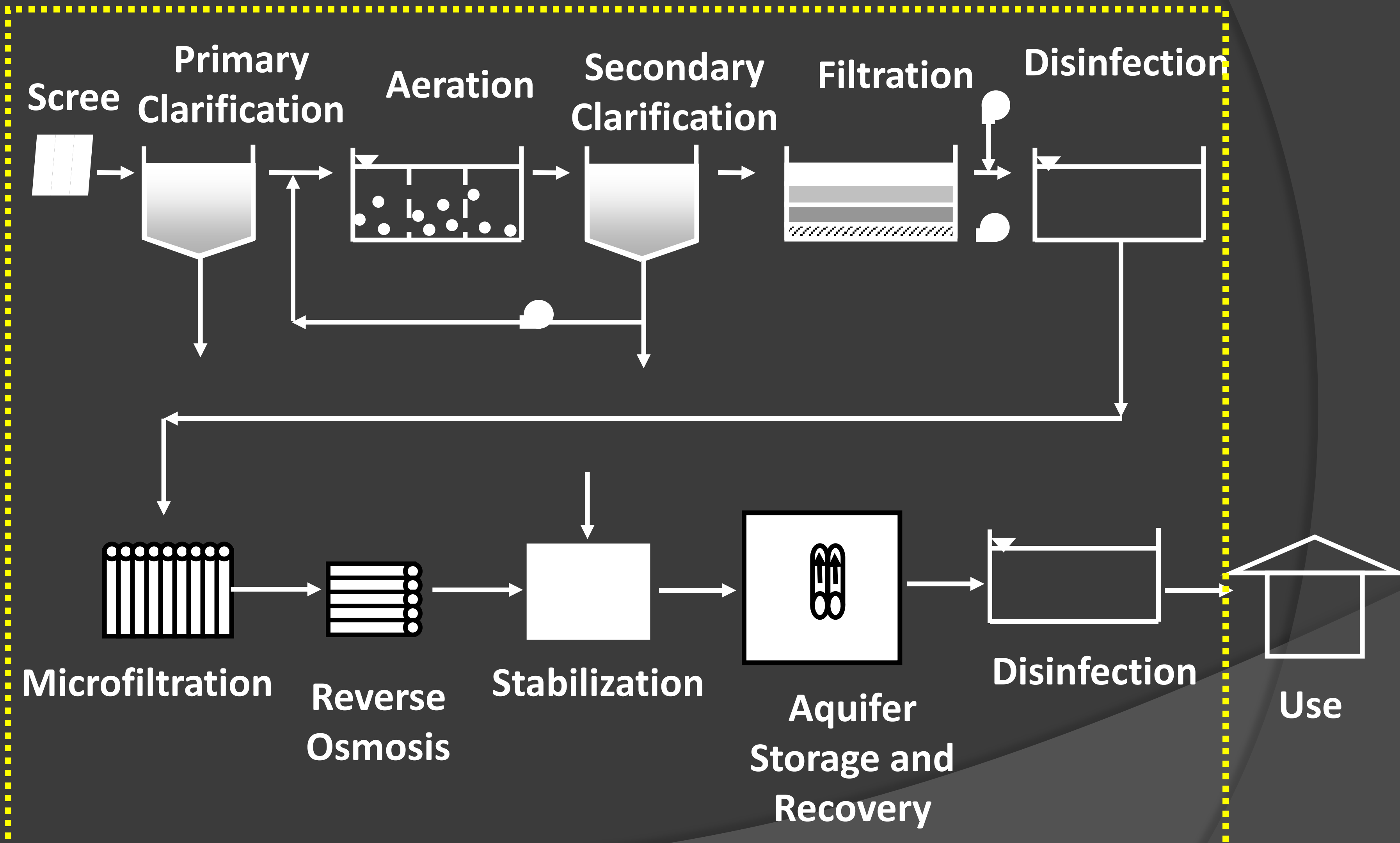
CAP Plant - System Diagram



CAP Plant Inputs

	Per 120,000 gallons of water
Concrete ($10^{-3}m^3$)	5.89
Steel (kg)	0.36
Energy (kWh)	637
PAC (kg)	4.48
$KMnO_4$ (kg)	0.37
Cationic Polymer (kg)	0.37
Alum (kg)	13.6
Chlorine (kg)	2.24

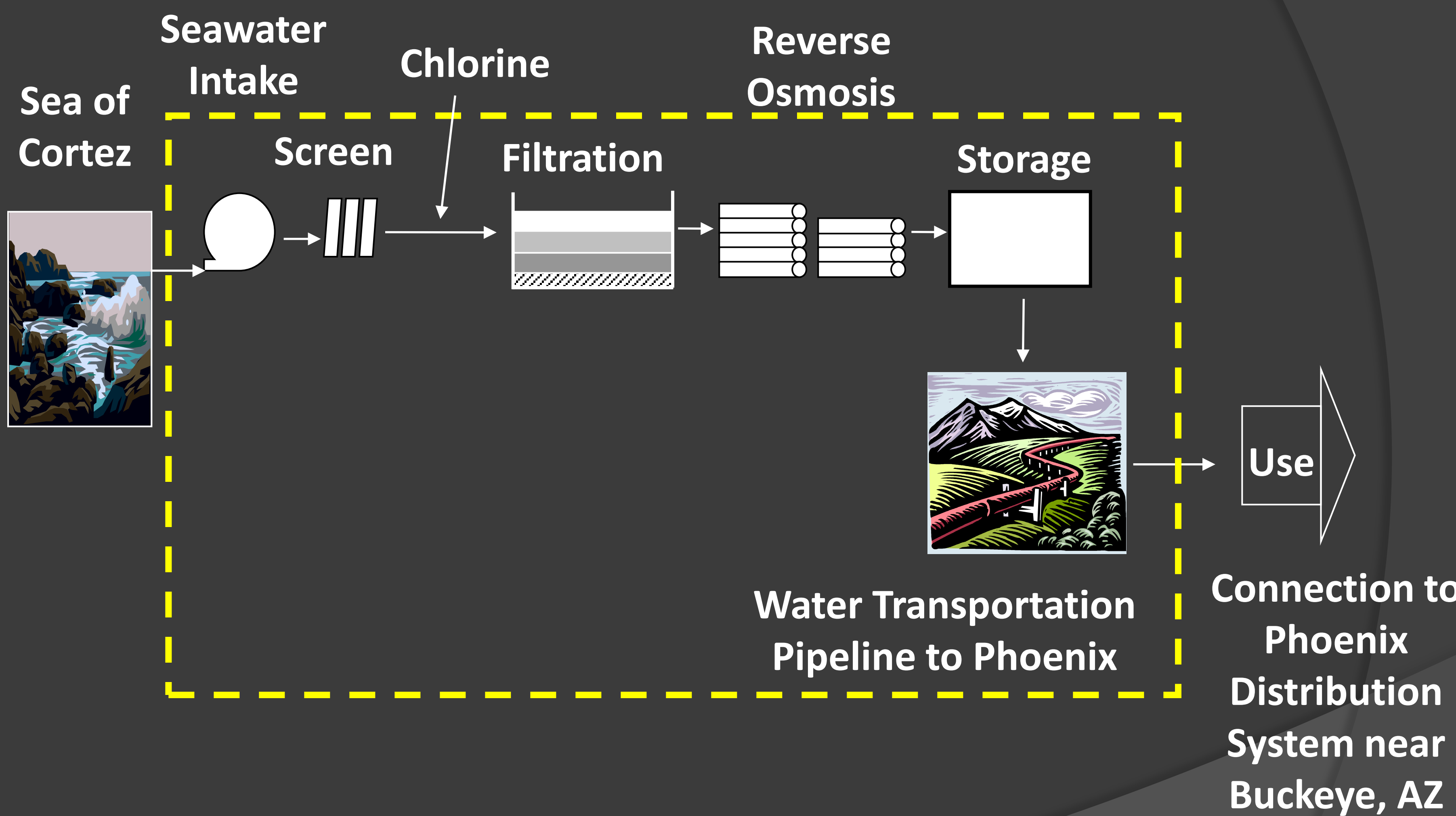
Reclamation Plant - System Diagram



Reclamation Plant Inputs

	Per 120,000 gallons of water
Concrete ($10^{-3}m^3$)	2.45
Steel (kg)	0.145
Energy (kWh)	427
Chlorine (kg)	5.60
Sulfuric acid (kg)	77.0
Anti-scalant (kg)	2.21
Lime (kg)	117

Desalination Plant - System Diagram

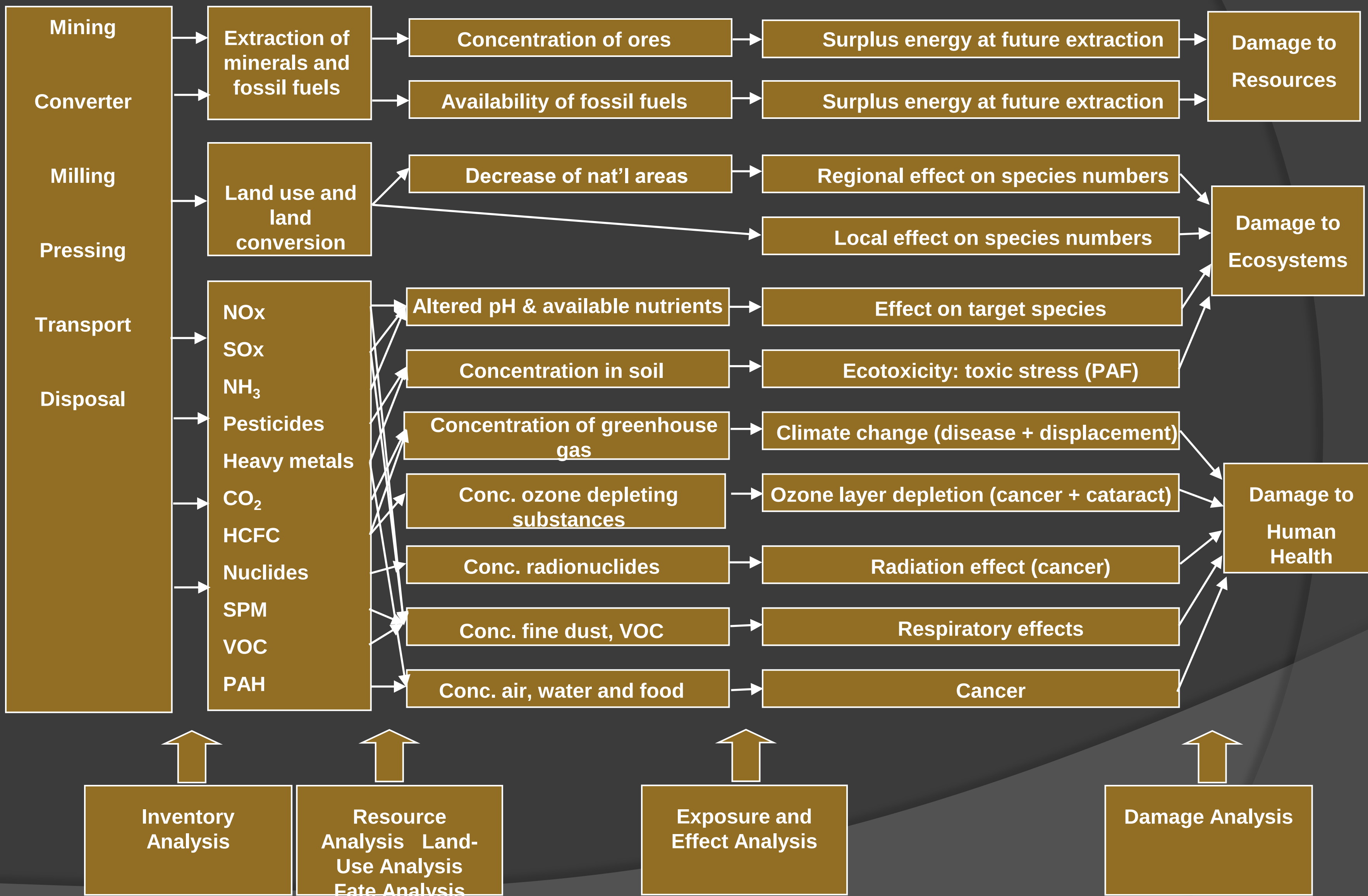


Desalination Plant Inputs

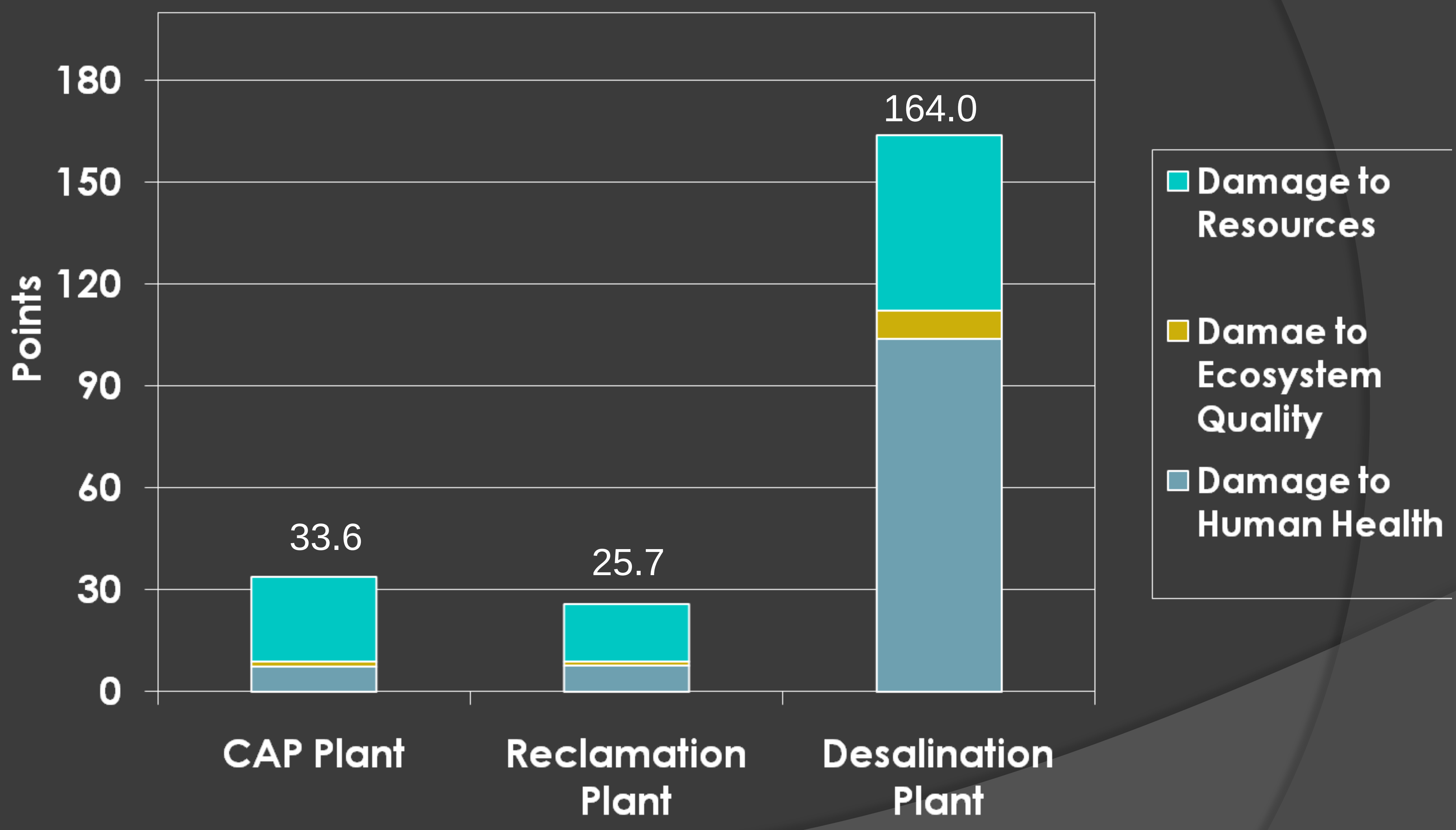
	Per 120,000 gallons of water
Concrete ($10^{-3}m^3$)	0.459
Steel (kg)	18.8
Energy (kWh)	3133
Chlorine (kg)	0.22
Sulfuric acid (kg)	9.10
Sand (kg)	0.377
Anthracite (kg)	1.13
Lime (kg)	91.0

Material and Energy Inventory/ Person Year

Eco-Indicator 99 Calculations



Comparison- Total Damages



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DigitalPhoenix:

Total carbon footprint in 2005

Table 1: total number of different units

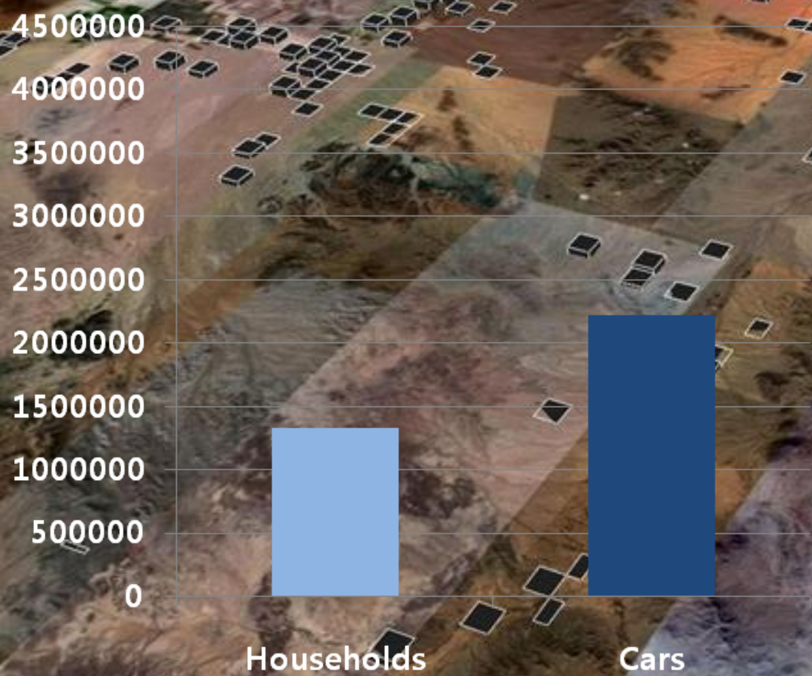
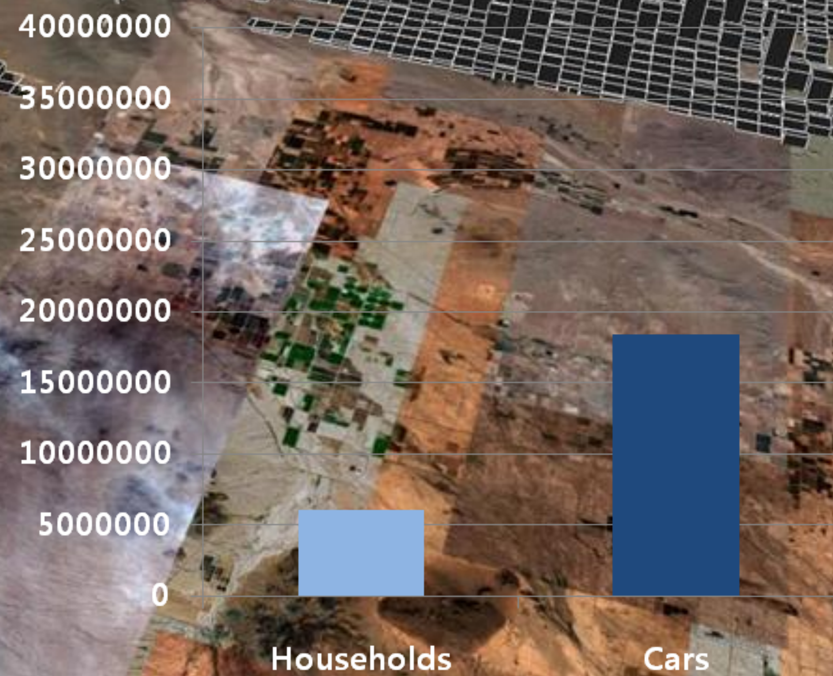


Table 2: total CO2 emissions (tons) by different units

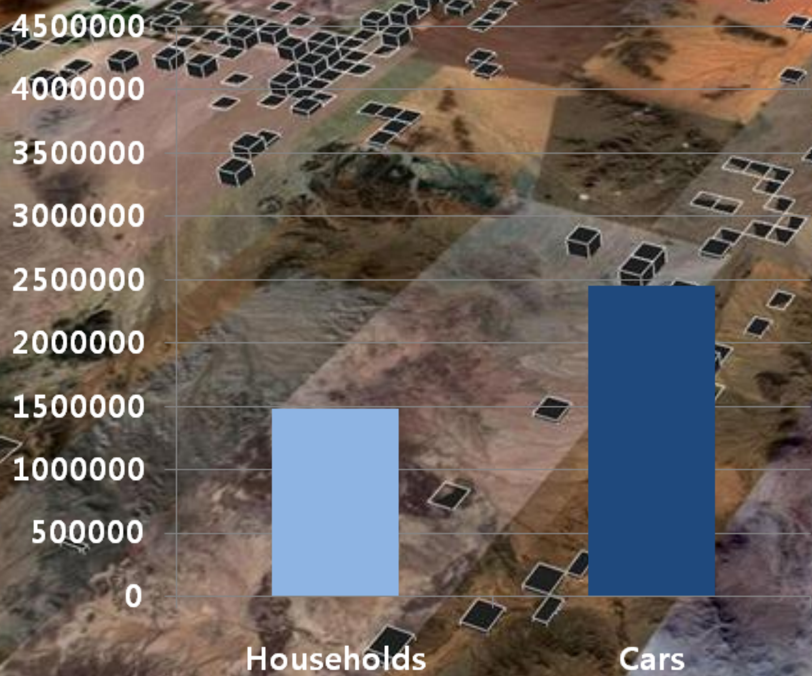


DECISION THEATER
ARIZONA STATE UNIVERSITY
www.decisiontheater.org

DigitalPhoenix:

Total carbon footprint in 2010

Table 1: total number of different units



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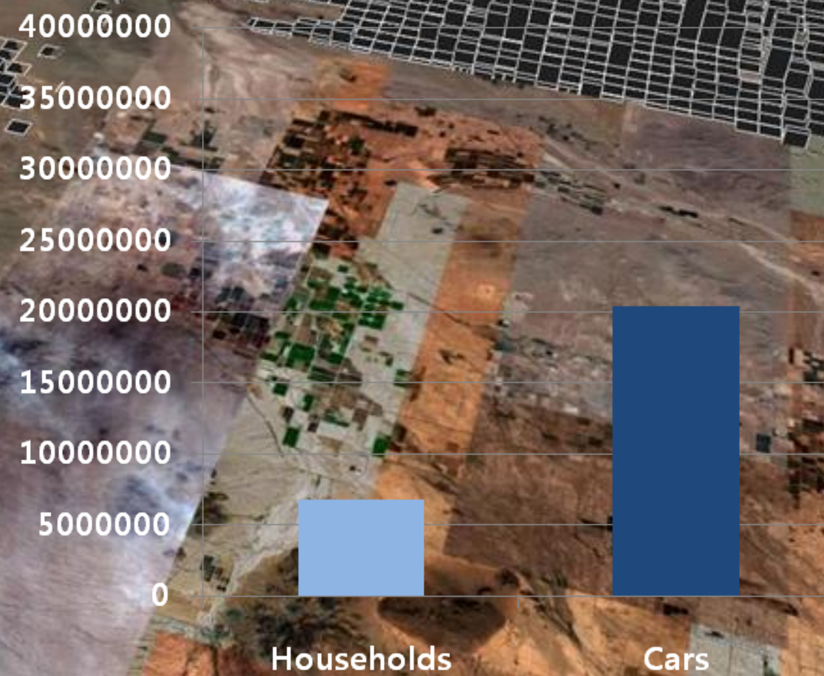

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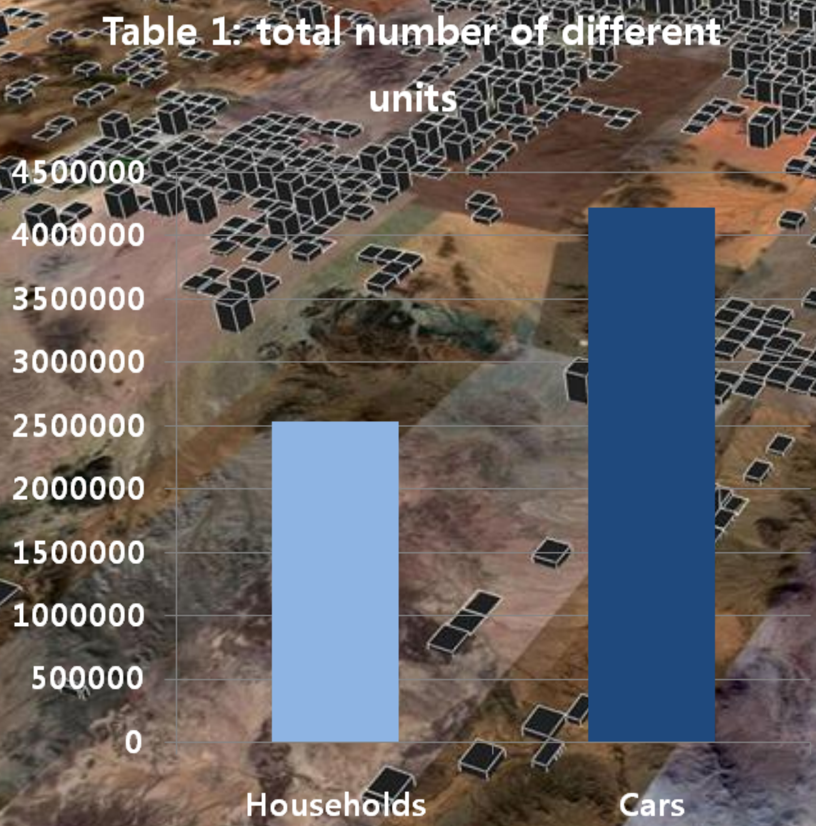
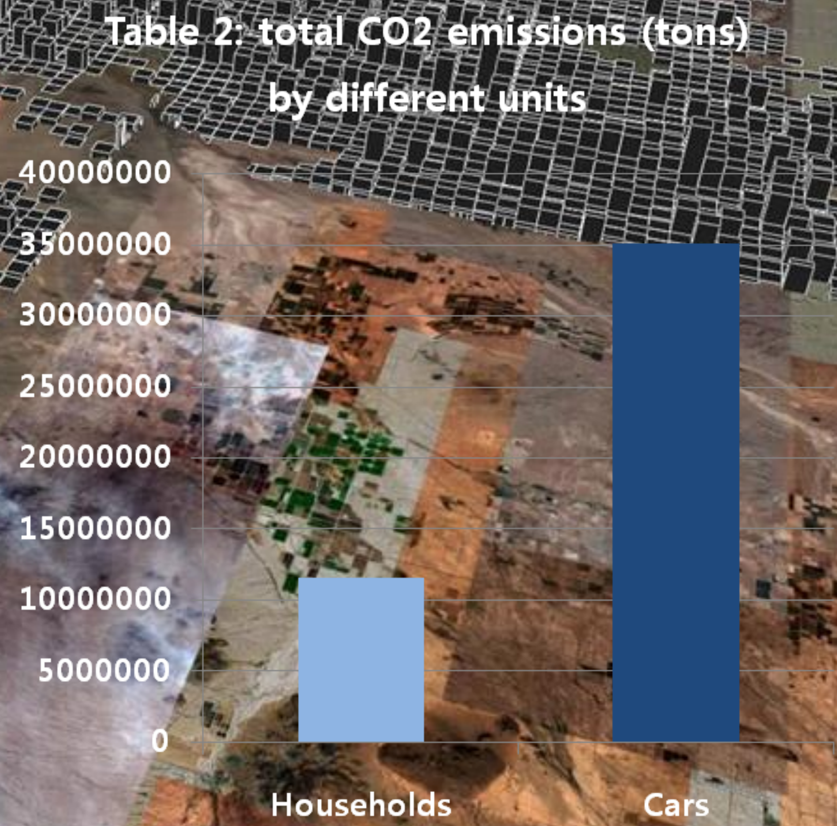
DigitalPhoenix:

Total carbon footprint in 2030





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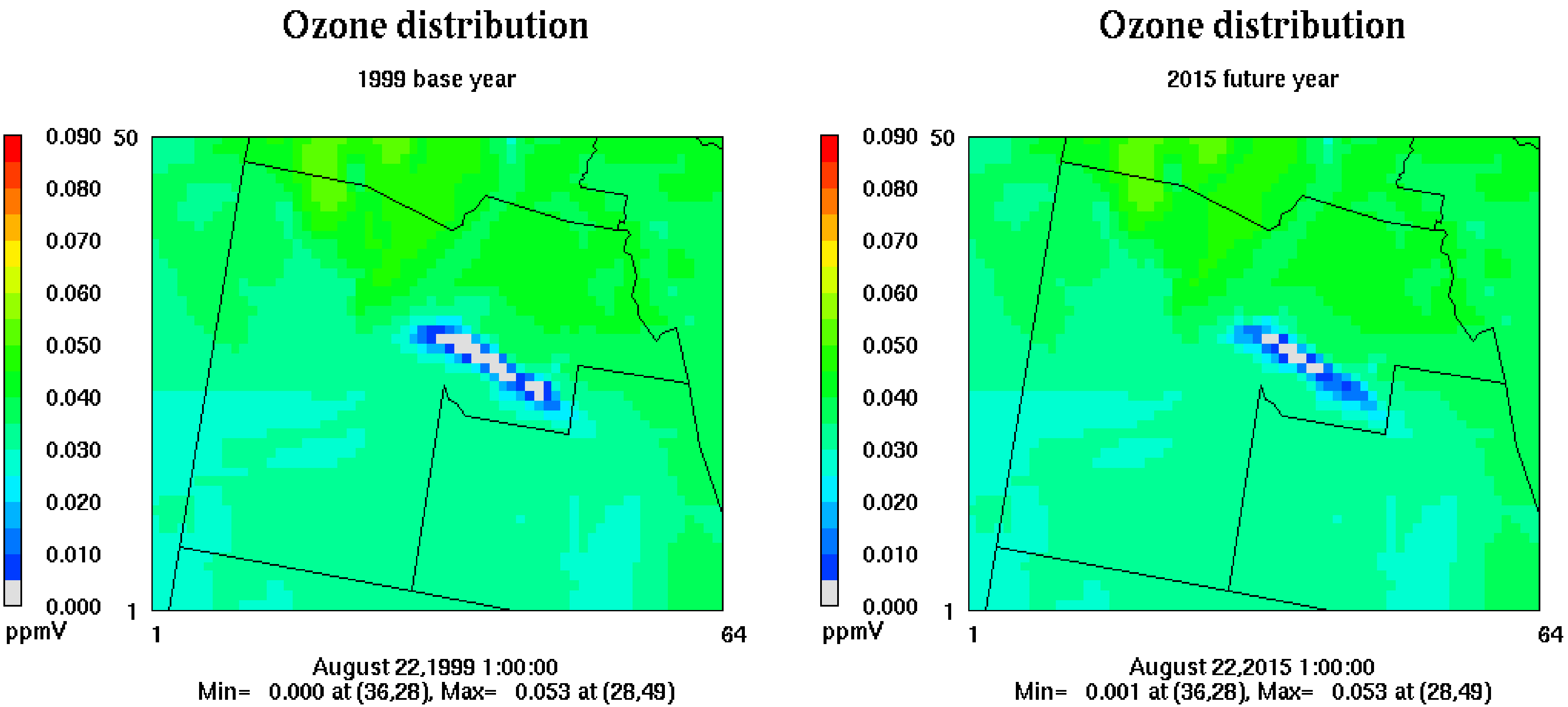
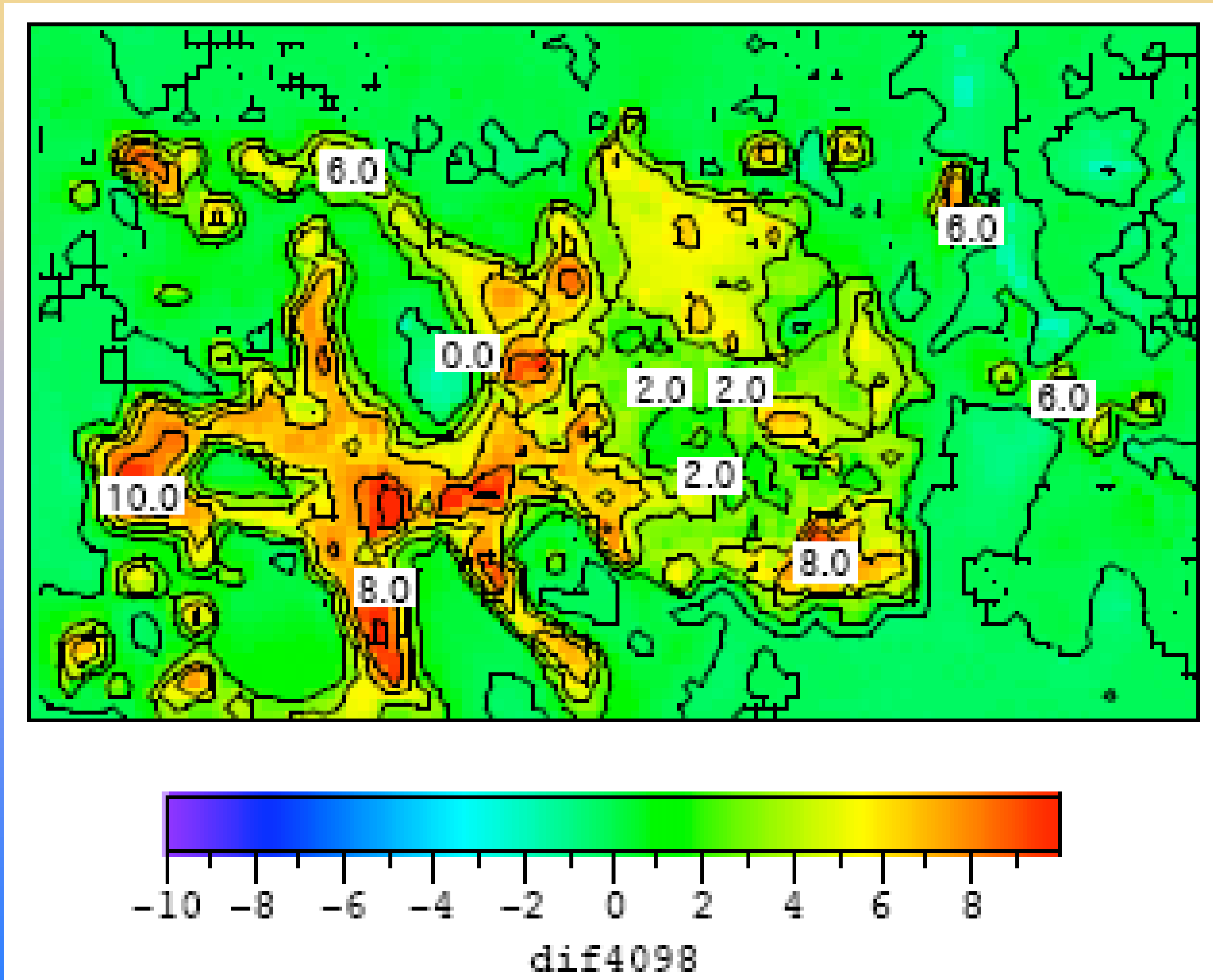
ARIZONA STATE UNIVERSITY

Ground-level ozone distribution 1999 VS. 2015



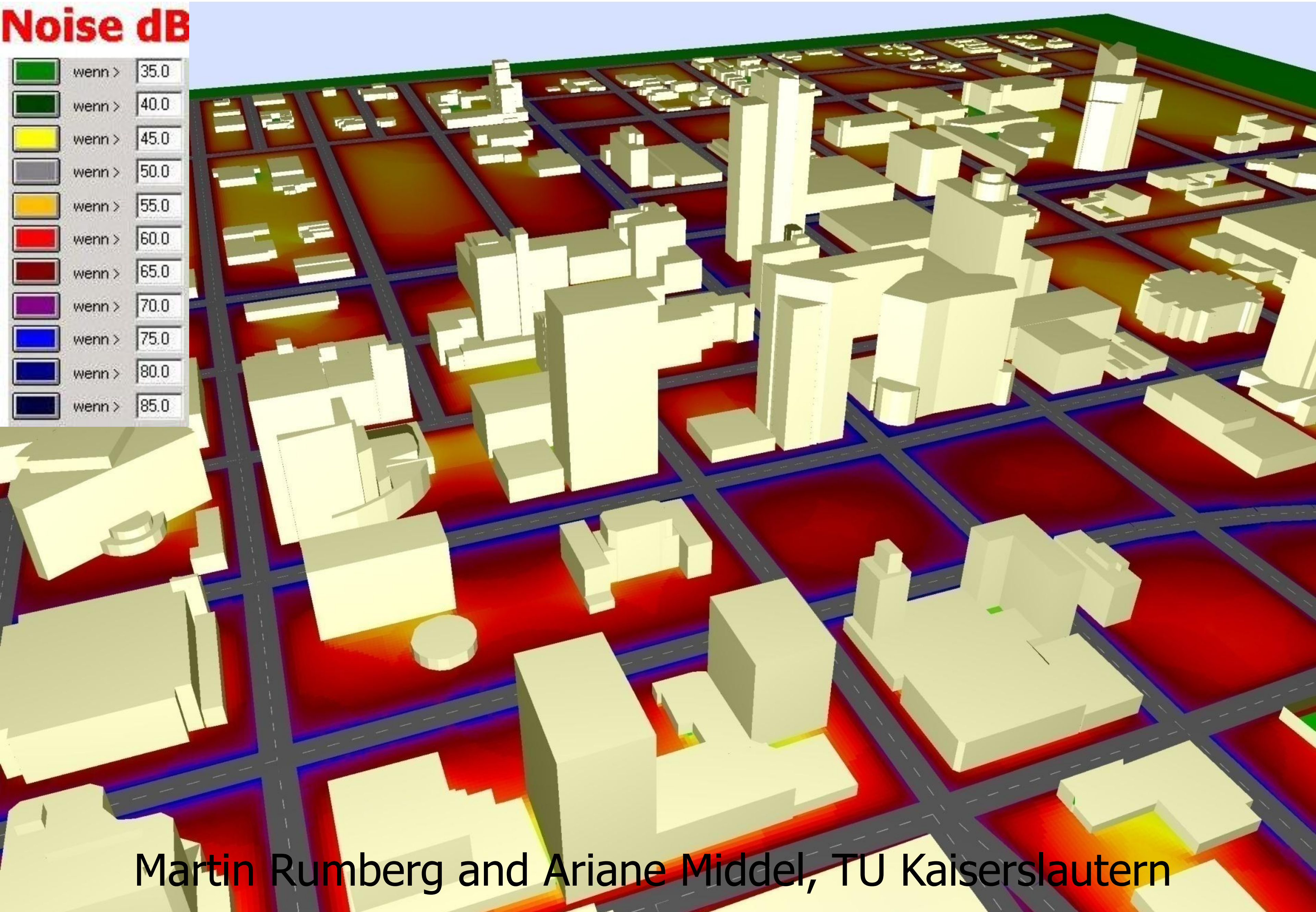
The animation shows a shortened ozone distribution in 2015 compared to 1999.

Difference in Temperature Contour in 1998 and 2040 (Predicted by UrbanSim)



Zehnder, Clarke, Guhathakurta, Li Crittenden

Noise – Predicted from Development Patterns and Traffic Patterns

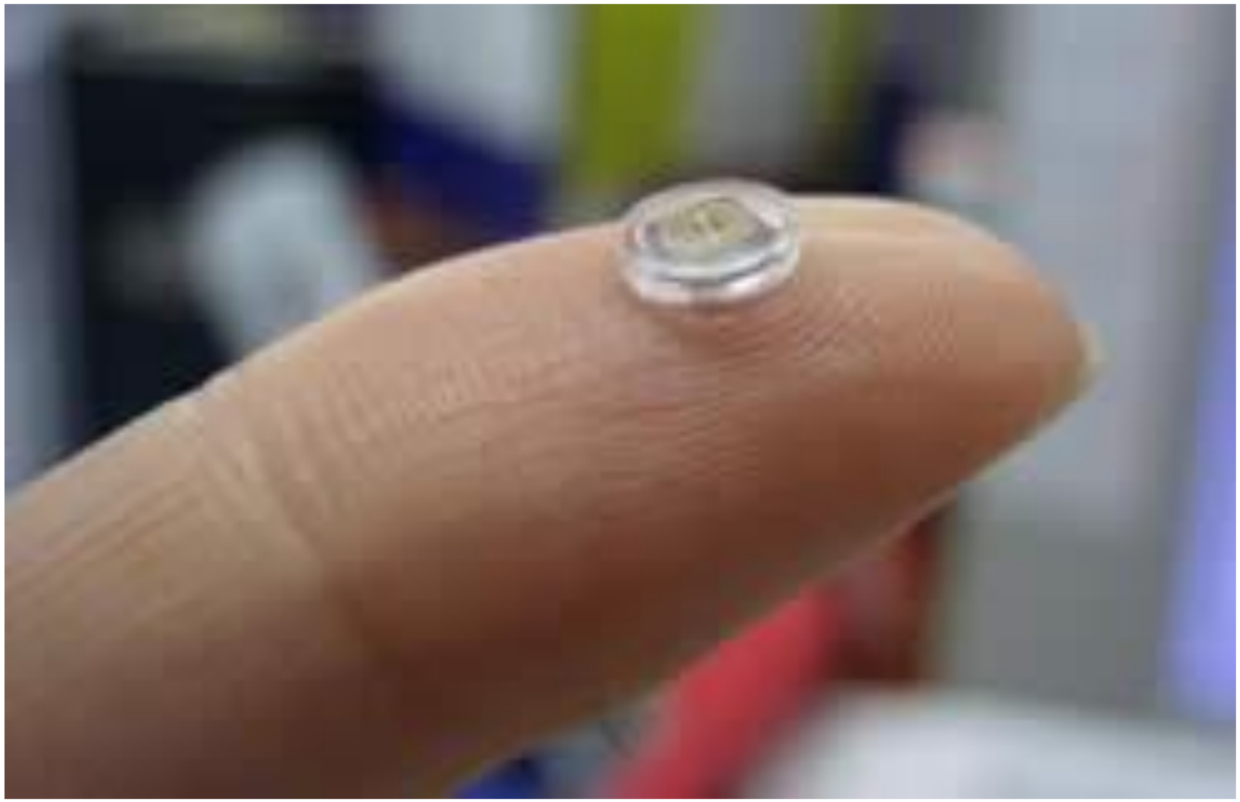


Martin Rumberg and Ariane Middel, TU Kaiserslautern

Cyber Infrastructure

- Tremendous Opportunity to Influence it for Urban Sustainability
- NAE Definition
  - Human
  - Hardware
  - Software
- Wireless Communication
- Sensors (Remote and Embedded)
- Modeling
- Data Mining and Fusion
- Visualization

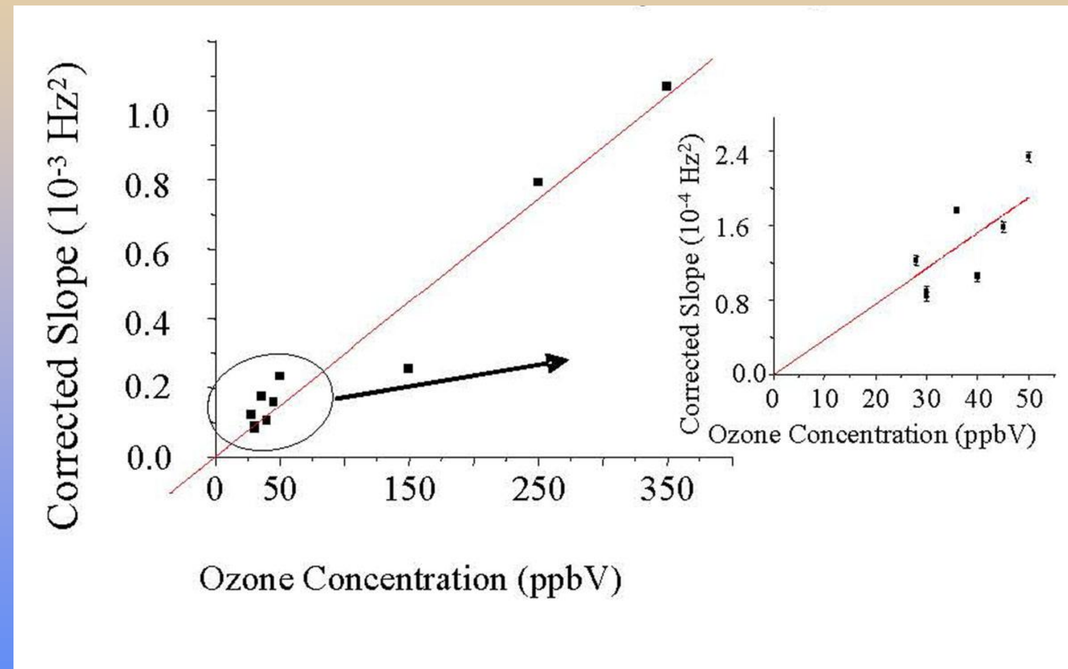
Computable tags for material flow and recycling



Radio Frequency Induced Device Indentification tag could be used for material flow analysis and include environmental, social and economic performance information

- Plastic Container of Liquid Soap deployed on Sep 05, 2009 in New York

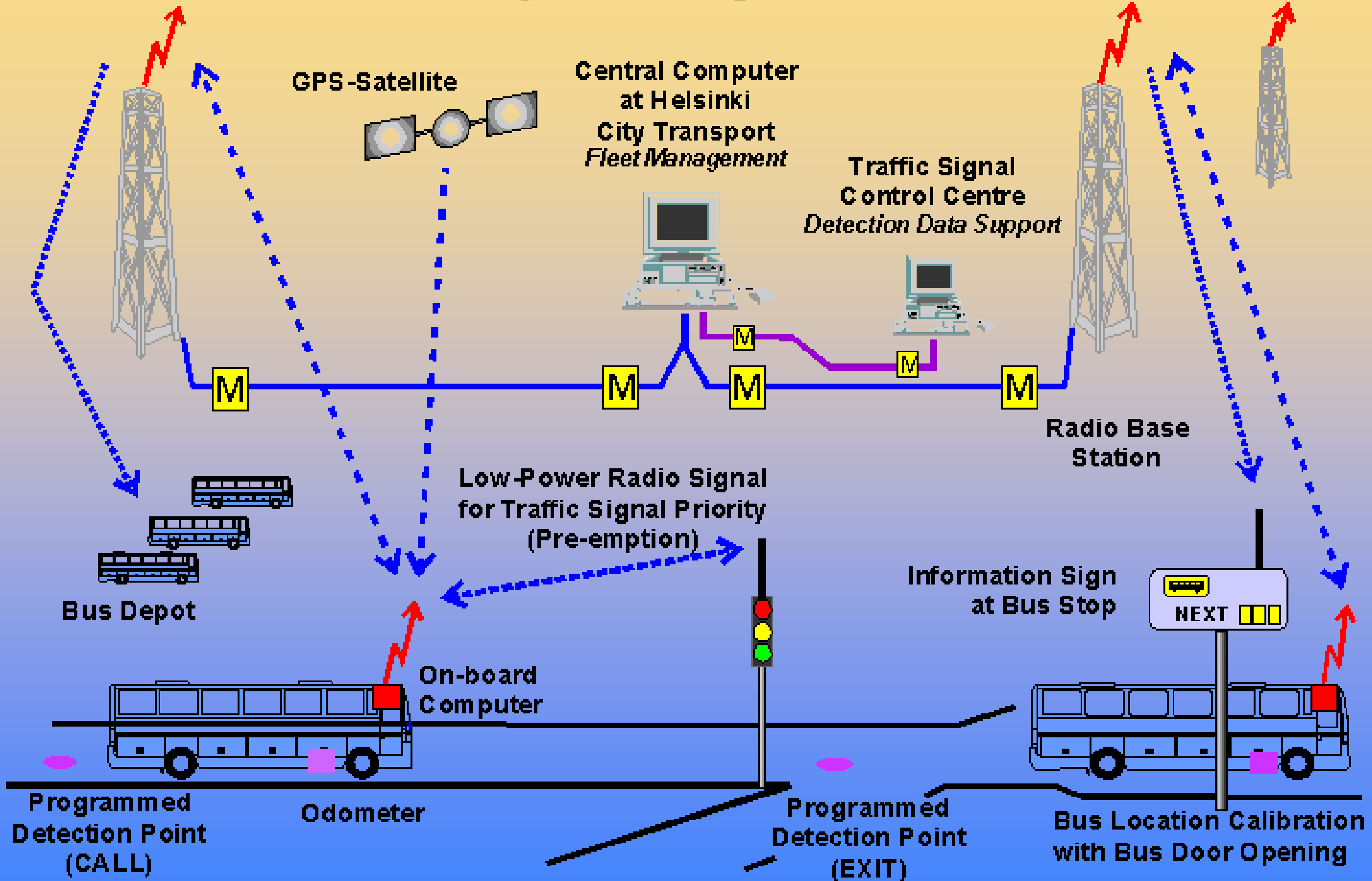
Tuning Fork Ozone Detector for a Cell Phone



Real-Time Ozone Detection Based on a Microfabricated Quartz Crystal Tuning Fork Sensor

Rui Wang [1,2], Francis Tsow [1,2], Xuezhi Zhang [3], Jhih-Hong Peng [2], Erica S. Forzani [1,2], Yongsheng Chen [3,#,*], John C. Crittenden [3,#], Hugo Destaillats [3,4,]* and Nongjian Tao [1,2,]*

Public Transport Telematics in Helsinki
Bus Priority and Passenger Information



What's Next? 3D modeling and Visualization

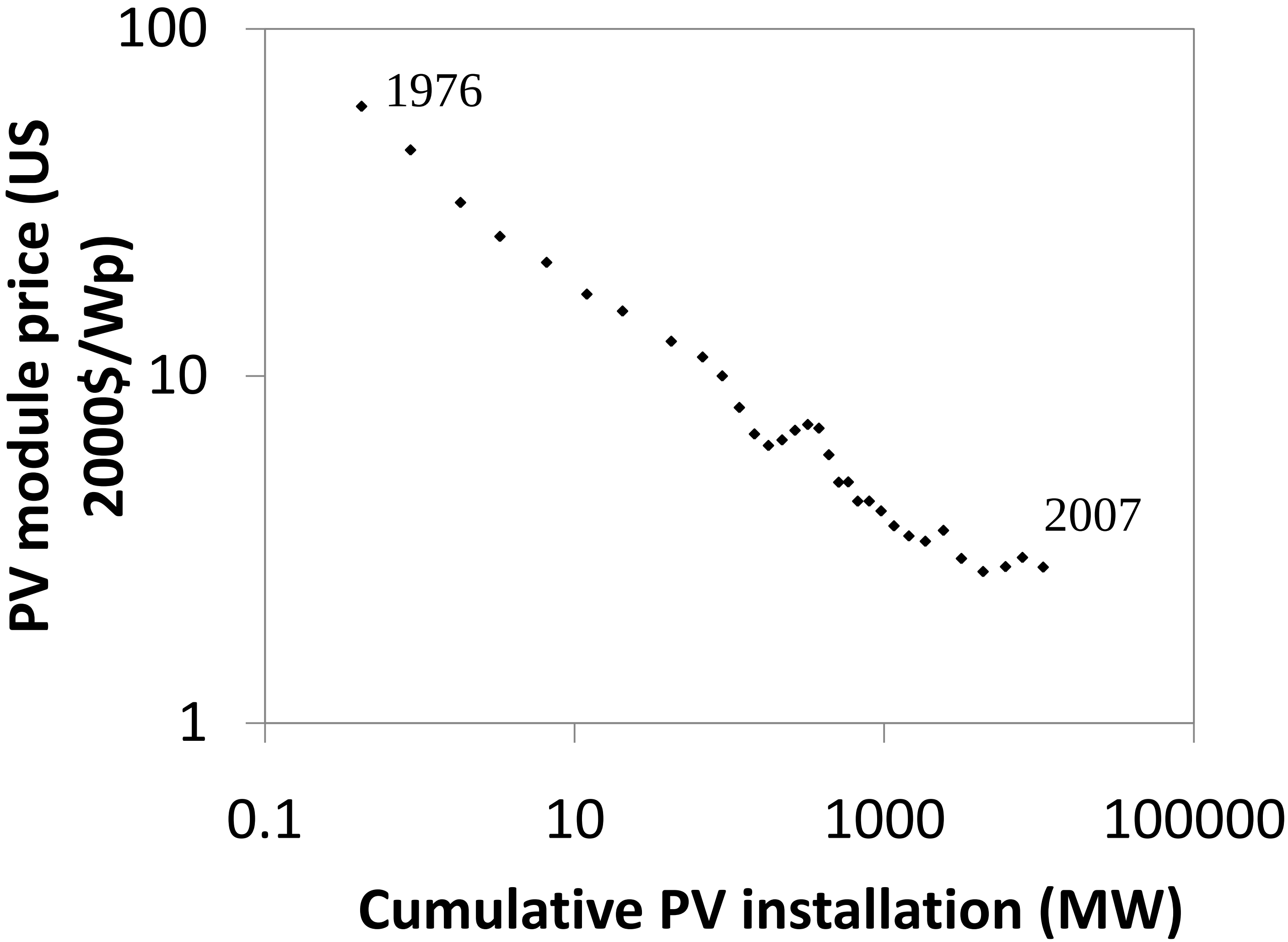
Los Angeles 1950s versus Today

Credit: WRI. Air and Water Quality has improved dramatically

Thoughts on Solving the Gigaton Problem

- High performance buildings
- Efficient power generation
- Electrification of transportation
- Enhancing ecosystem services or avoiding their destruction
- Mandates for product performance and take back
- Market drivers for energy efficiency (SEAR 16 versus 13 etc.)
- Smart grid
- Distributed power and water generation
- Biomass reforming to create fuels, commodity chemicals, specialty chemicals
- Integrated resource recovery (metals, nutrients, energy etc from waste or shall I say byproducts)
- Policy issues that relate to the above
- Econometrics and economic flows that favor the above
- Devise a market or stipulate mandates that gets gigainvestors and gigaentrepreneurs on task.

Experience Curve for PV



Credit Eric Willaims, Sources: PV module prices from Margolis (2002) and EIA (2008). Module installations from Margolis, NREL (2006) and Solarbuzz (2008, 2009)

Two Planets meet in Space

- **Arranging our ideological deck chairs on the Titanic**
- **Sooner or later, the earth will come into equilibrium; that is, resources generated will equal resources used. There are two fundamental questions: 1) Will humans be part of the new earth that is in equilibrium. 2) If humans are, will it be a comfortable place or a place wrought with armed conflict and social injustice because of limited resources.**

Credit: Volker Karthopf

America's Grand Challenge - A Sustainable Future

- John F. Kennedy inaugural address – January 20, 1961.
- Inspired us to sacrifice for the greater good. Why not now?
- Create an anthrosphere that exists within the means of nature. Uses resources that Nature can provide and generates wastes the Nature can assimilate.
- Provide the developing world opportunities to lead useful and productive lives
- Become a global leader in developing more sustainable technologies
- Achieve energy self-sufficiency by 2020 with efficiency, renewables and reduce Carbon Emissions 70%

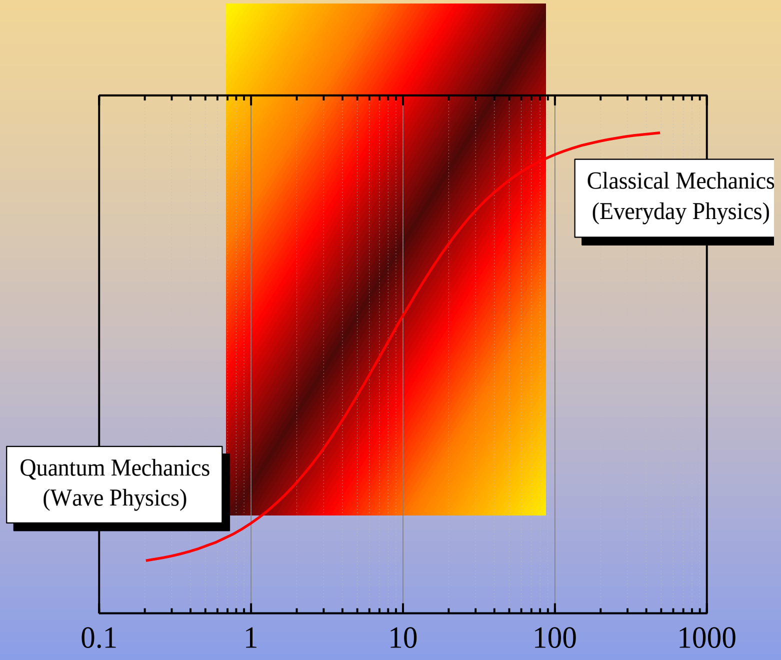
- Become the most generous country in the world again by providing medicines, technology transfer, and aid to people in developing nations everywhere
- Obama?
- **Sustainable Differentiation =Innovation (e.g., Carbon Advantage)**

Five Horsemen of Technological Development and Their Convergence

- Nanotechnology
- Biotechnology
- Information Technology
- Cognitive Technology
- Robotics

Nano is Different

- At the micron (1,000 nm) and larger scale, classical physics determines properties.
- At the Angstrom (0.1 nm) scale, quantum mechanics determines properties.
- At the nanometer scale, fundamental properties depend on exactly how big the particle is.



- The nanoworld

Stages of Nanotechnology Development

- Technological Complexity
  - increasing

- **First Generation ~2001: Passive nanostructures**
  - Nano-structured coatings, nanoparticles, nanostructured metals, polymers, ceramics,
  - Catalysts, composites, displays

- **Second generation ~Now: Active nanostructures**
  - Transistors, amplifiers, targeted drugs and chemicals, actuators,
  - adaptive structures, sensors, diagnostic assays, fuel cells, solar cells,
  - High performance nanocomposites, ceramics, metals

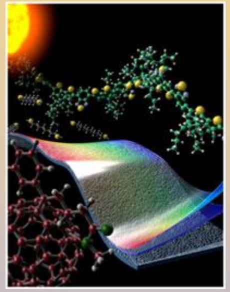
- **Third Generation ~ 2010: 3-D nanosystems and systems of nanosystems**
  - Various assembly techniques, networking at the nanoscale and new architectures,
  - Biomimetic materials, novel therapeutics/targeted drug delivery

- **Fourth Generation ~2015 Molecular Nanosystems**
  - **Molecular devices "by design", atomic design, emerging functions,**
  - **biological, and neural connections.**

Source: Barbara Karn's presentation, US Environmental Protection Agency

Products and Applications

- Cheap and clean energy
  - Prototype solar panels incorporating nanotechnology are far more efficient than standard designs in converting sunlight to electricity, promising cheap solar power in the near future.

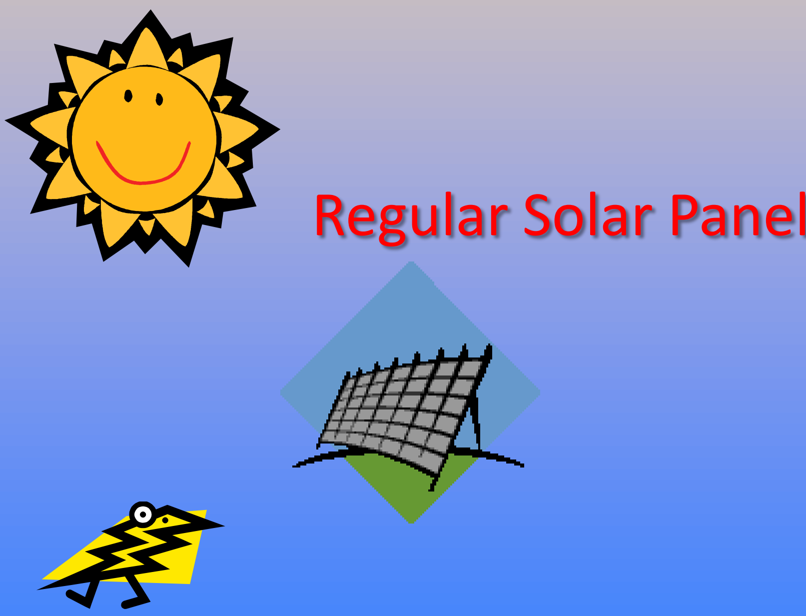


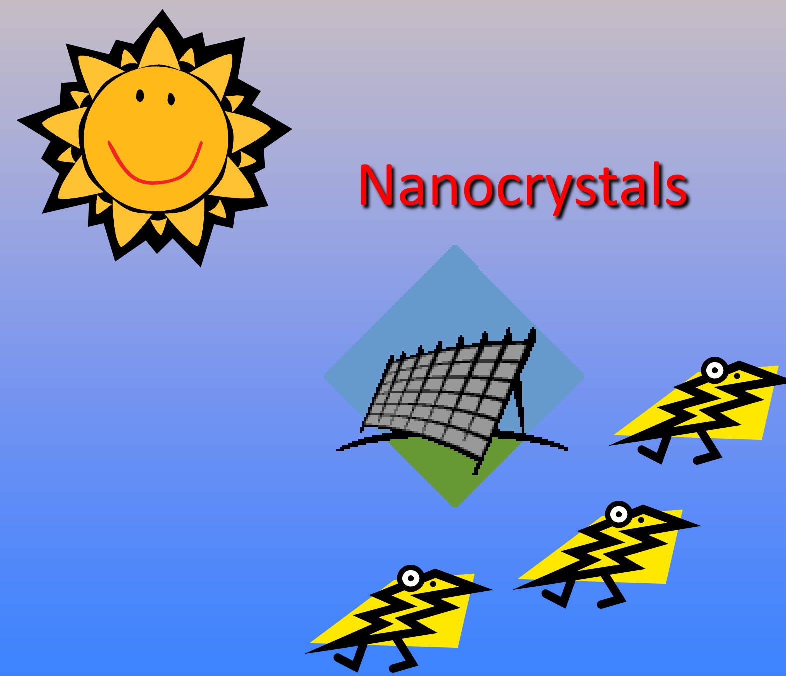
  - Nanotechnology is already being used in new batteries, and nanostructured materials look to greatly improve hydrogen storage materials and catalysts needed to realize fuel cells for alternative transportation.

Photo credit: New solar panel films incorporate nanoparticles to improve performance (Gui Bazan, UCSB, graphic by

Greater Efficiency of Nanotech

- Nanocrystals
  - More electrons – 3 to 1
  - More energy produced





Products and Applications

- Clean water
  - Nanotechnology could help meet the need for affordable clean water through inexpensive water purification, as well as rapid, low cost detection of impurities. Researchers already discovered unexpected magnetic interactions between ultra small specks of rust, which can help remove arsenic from drinking water.

Photo credit: Nanorust Cleans Arsenic from Drinking Water. Image courtesy of CBEN/Rice University

Products of Nanotechnology:

- Source: Barbara Karn's presentation,
- US Environmental Protection Agency

End User Applications (9%):

- Tennis Balls, Rackets
- Clothing
- Cameras
- Respirators
- Razor Blades
- Cosmetics
- Beer Bottles
- Sunscreens

Industrial Imaging (8%):

- TEM
- STEM
- SEM
- AFM
- E-Beams
- X-Ray, Confocal Microscopes

Test & Measurement (9%):

- Strain
- Film Thickness
- Surface Topography

Software (4%):

- Modeling
- AFM software
- Controllers for Microscopes
- CAD navigation

Capital Equipment (15%):

- Positioners
- Cantilevers
- Coaters
- Probes/Manipulators
- Lithography:Masks, Resists
- AFM's

Components (8%):

- Transistors
- Fillers
- Catalytic Converters
- Fenders
- Mirror Housings
- Fuel Cells
- Step Assists
- Polarizers/Wave Plates
- Displays-OLED
- Surgical Fusions

Materials (44%):

- Nanotubes
- Fullerenes
- Quantum Dots
- Metal oxides
- Dendrimers
- Nanoclays
- Nano metals – Gold, Silver
- Nanocomposites

Therapeutic System (3%)

- Women's cream designed for short-term use (Estrasorb)
- Drug for chemotherapy-induced nausea (Emend)
- An antibacterial protocol available to doctors and researchers (NanobacTX)
- Nanoparticle-based nutraceutical spray to deliver nutritional supplements
- through the cheek lining
- Automating equipment for biomedical sample preparation process
- Immunosuppressive drug (Rapamune)
- Ultrasmall silver nanocrystals (Acticoat Burn Dressing)

EFFECT OF NANOTECHNOLOGY--AUTOMOTIVE

Lightweight	Less Fuel; Fewer GHG, Life-cycle impacts
More efficient Catalysts	Less Tailpipe Pollution
Better Coatings	Fewer Solvents, Longer Life, Less Renewal; Safer Bad Weather Driving
Sensors	Better Fuel Economy, Climate Control, Fewer Tailpipe Pollutants
Tires	Less Wear, Longer Lasting (Less Disposal), Fewer Accidents
Hybrids/Fuel Cells	Less Polluting

Source: Barbara Karn's presentation, US Environmental Protection Agency

EFFECT OF NANOTECHNOLOGY--ENERGY

Fuel Cells Solar Cells	Less use of Fossil Fuels, Less pollution
Batteries	Less Material, Longer life-less disposal

EFFECT OF NANOTECHNOLOGY--ELECTRONIC

Memory/Hard Drives	Better Environmental Data and Information
Displays (OLED)	Less Energy used
Anti-static Coatings	Less Cleaning, more Efficiency

Source: Barbara Karn's presentation, US Environmental Protection Agency

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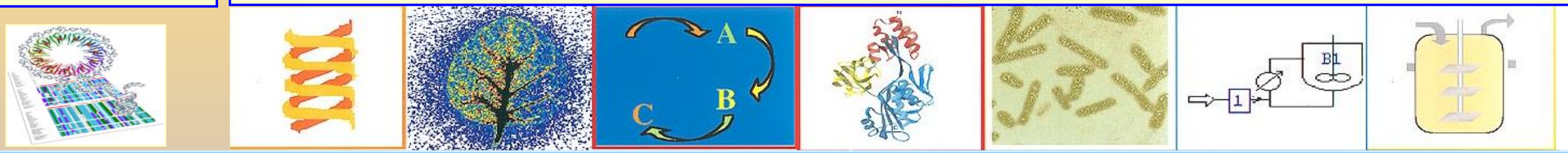
Biotechnology for Sustainability: Innovative and Disruptive

Bioinformatics	Genomics	Gene Expression	Metabolic Path Eng.	Protein Engineering	Micro-Biology	Bio-Engineering	Fermentation



Enabling Technologies

Further Building On:

Platform Technologies

	Genome	Proteome	Life Networks
Control & Manipulate	Directed Evolution	Protein Engineering	Cell Systems
Digitize & Analyze	Functional Genomics	Protein Function	Chemo Genomics
Discover	Genomic Sequencing	Protein Structure	Protein & Cell Signaling

From Barbara Miller- Dow

Biotechnology for Sustainability: New Industrial Revolution ?

- **OLD CHEMCIAL PROCESS**

- **Many Steps**
- Glucose
- Ca-Arabonate
- Ca-Ribonate
- Riobolactone
- Ribose
- Ribitylxylidine
- Phenylazo-RX
- **VITAMIN B2**

→

- **Hazardous**
- **Waste**
- **Generation**

- **NEW INDUSTRIAL BIOTECH PROCESS**

- **One Step**
- Fermentation with
- genetically enhanced
- microorganism
- **No**
- **Hazardous**
- **Waste**
- **VITAMIN B2**

Science and Applications Knowledge Base

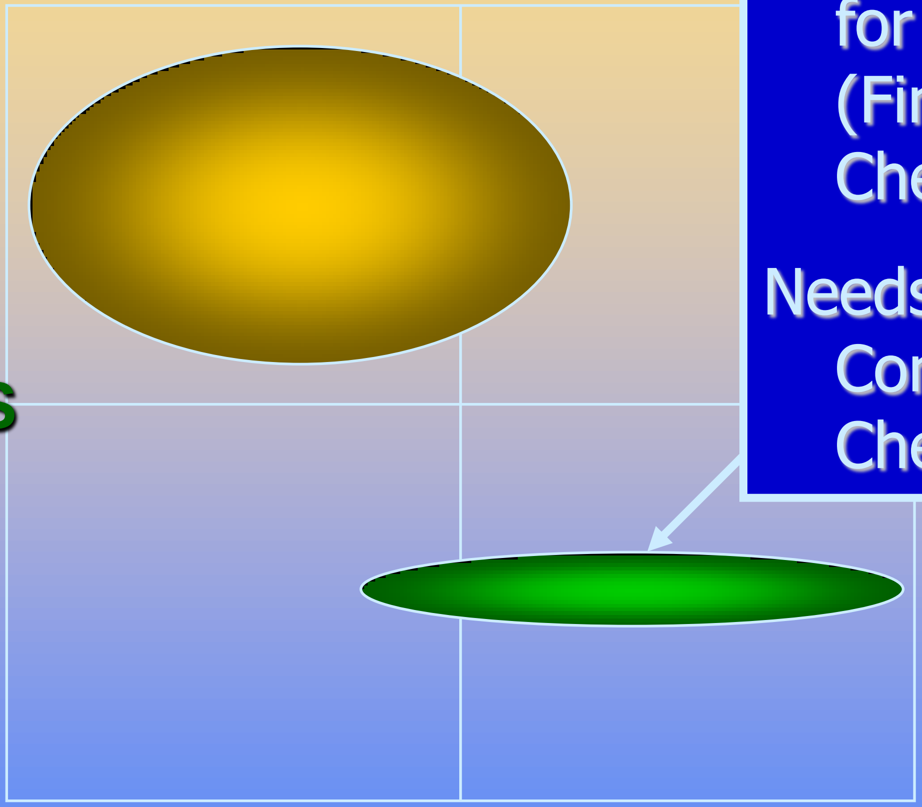
Fair Development for Specialty (Fine) Chemicals

Needs Work on Commodity Chemicals

Fossil/ Petroleum

FEEDSTOCKS

Biobased/ Renewable



Chemical/Thermochemical

Biocatalytic

PROCESSES

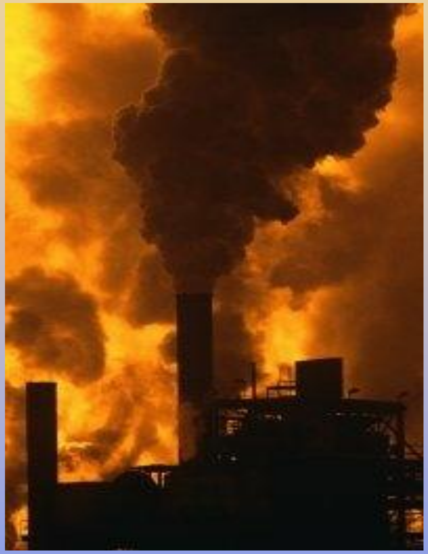
Source: Council for Chemical Research

In Early Stages of Development

Industrial Biotech Offers Some New Solutions to Environmental Problems

- Water
- pollution

- Hazardous
- Waste Generation



- Air
- Pollution

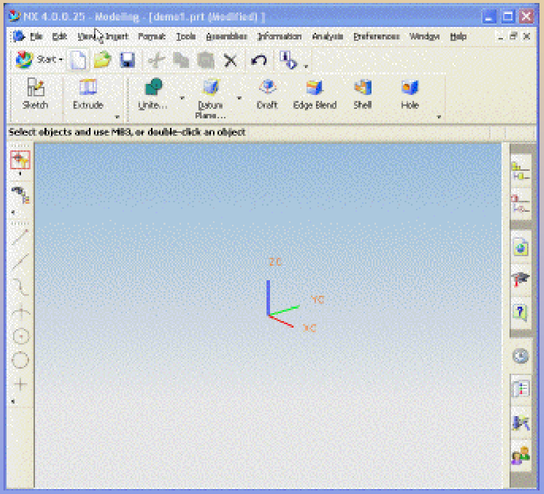
- Climate
Change
Emissions

Five Horsemen of Technological Development and Their Convergence

- Nanotechnology
- Biotechnology
- Information Technology
- Cognitive Technology
- Robotics

Information Technology

- **Manufacturing:**
  - The system can supply important input to general business management, and identify opportunities for reduction in use of energy, material, and wastes by using computer integrated manufacturing (CIM)
  - Computer-aided designing (CAD) can help in reducing product development cycle.



  - Virtual reality simulation can be used to speed up test methods.

Information Technology

- **Transport:**
  - Teleworking and teleconference substitute for local and long distance travel.

  - Microprocessor engine systems can save fossil fuel and reduce pollution.
  - Advanced transport telematics (ATT) can improve transport efficiency and road safety.
  - Intelligent transport systems can reduce travel time, improve traffic flow and help to make the roads safer.

Information Technology

- **Agriculture:**
  - Land information system prepared using geographic information systems (GIS) and remote sensing can help farmers plan their activity and facilitate decision making and planning at the local level.
- **Environment:**
  - IT systems can provide improved access to environmental information to citizens, authorities at every level, NGOs, and businesses for environmental monitoring and management.
  - GIS and remote sensing can be used to map resources, land-use patterns and environmental factors. This could help bring about more effective planning, management, and decision-making with regard to the environment.
- **Education:**
  - Multimedia teaching packages can be used for formal and informal education.
  - On-line courses using Internet can be used, with no constraint on distance separating the teacher and the student.

Five Horsemen of Technological Development and Their Convergence

- Nanotechnology
- Biotechnology
- Information Technology
- Cognitive Technology
- Robotics

Cognitive Technology

- **The ability to understand neural functions may well have profound effects on human performance and well being.**
- **Better understanding on the data mining process of human brain will improve quality of life and reduce resources use, such as computer-aided reading, machine design, smart manufacturing, etc.**
- Basic understanding of the philosophy, cultural differences, linguistics and anthropology is the starting point.
- The study on visual and sensational cognition can provide better facilities to enable disabled communities to better interact and contribute to the society. It also improves social equity.
- Cognitive technology will lead to improvement of pedagogy for sustainable society concept, which will lead to a better social decision-making.
-

Two Planets meet in Space

- **Arranging our ideological deck chairs on the Titanic**
- **Sooner or later, the earth will come into equilibrium; that is, resources generated will equal resources used. There are two fundamental questions: 1) Will humans be part of the new earth that is in equilibrium. 2) If humans are, will it be a comfortable place or a place wrought with armed conflict and social injustice because of limited resources.**

Credit: Volker Karthopf

Questions

(Yes this is a real fish)

Future Work

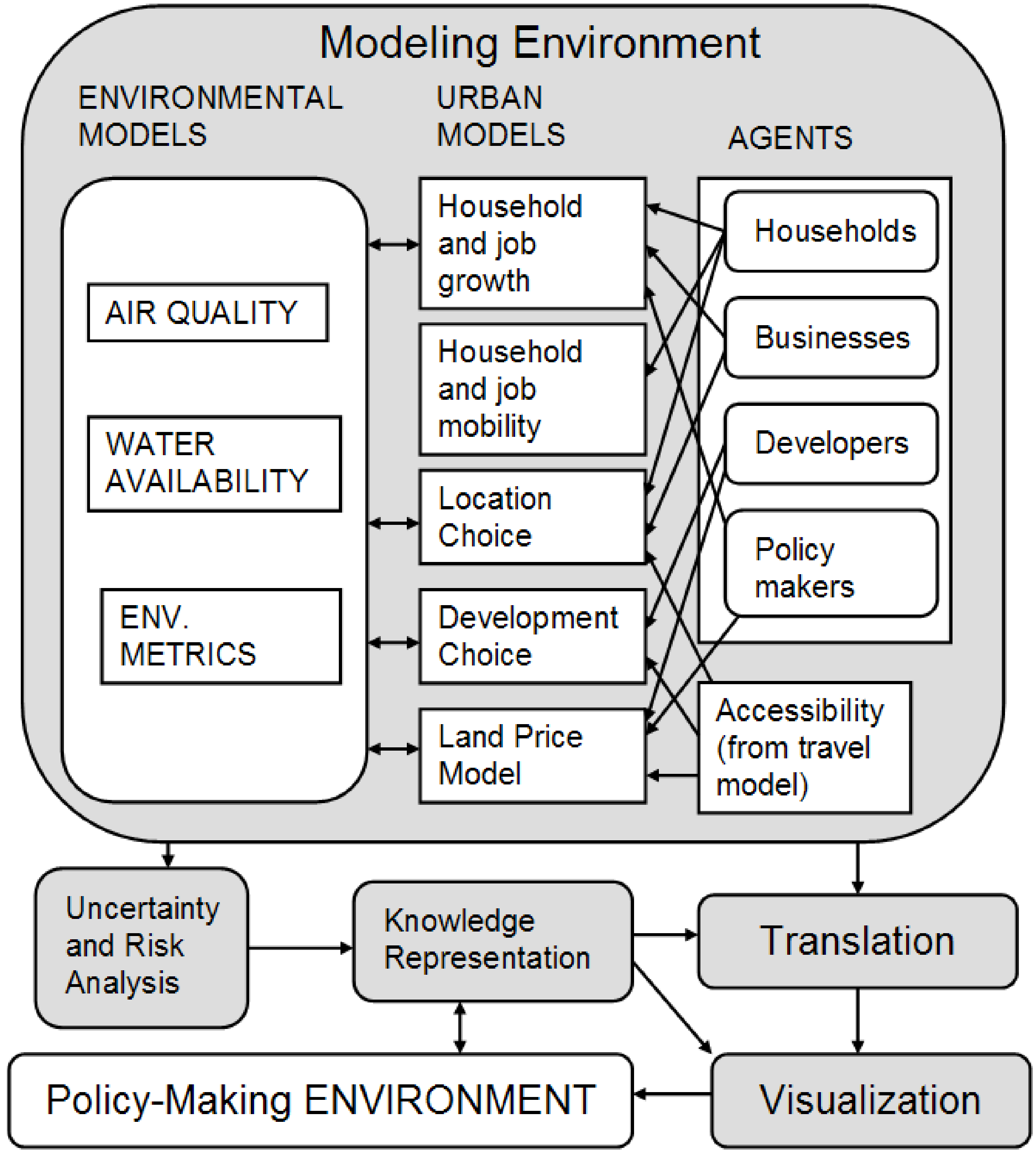
- Include other built infrastructure (commercial buildings, ground transportation)
- Examine scenarios between these two extremes scenario storylines (IPCC, 2001):
  - (1) ***Tech World*** - economic growth is extremely high, natural resources availability is assumed to be unconstrained, new technology yields new products and uses new materials, and the environment is not a priority;
  - (2) ***Green World*** - strong economic focus on green products, practices and processes, sustainability becomes a major ideological driver for society, rapid technological change focuses on lower material intensities, and industrial ecology is widely practiced and regions internalize environmental externalities.
- Include other urban systems such as energy, water, etc…

Conclusions - Land Use Scenarios

- Three General Plan Scenario (slow growth, General Plan growth, fast growth)
- Dispersed Polynucleated City
- Strong Central City
- Resort Mecca
- Transportation Influenced
- General Plan Scenarios, buildout population constant, buildout year varies
- Maricopa County population totals constant, Phoenix totals allowed to vary

Workflow showing the interface between the models and policy-making environment

(2 Million lines of code for Land Use Simulation)



Exiting Tools – Agent Modeling and Geospatial Modeling

- The past decade has witnessed a significant increase in the quality and quantity of geospatial information from various sources. Consequently, the quest for knowledge from the massive geospatial information for scientific, commercial and decision-making activities has posed new challenges for the geospatial research community. While conventional spatial statistics methods remain their power and popularity in numerous studies, many new techniques and approaches have appeared in response to the newly available geospatial data, which is essentially massive, complex, incomplete and uncertain. A variety of analysis and modeling approaches have been brought into geospatial domain such as cellular automata, agent-based modeling, and qualitative and fuzzy reasoning. These techniques are efficient and effective in discovering hidden structures, patterns and associations within geospatial data. On the other hand, emerging visualization and interaction technologies provide a powerful tool for obtaining additional insights into geospatial information for spatial analysis and modeling process. There has been an increasing convergence of the analytical reasoning and visualization towards creation and discovery of geospatial knowledge for real world applications.

Object tags

- Tagging of objects—Ford VIN

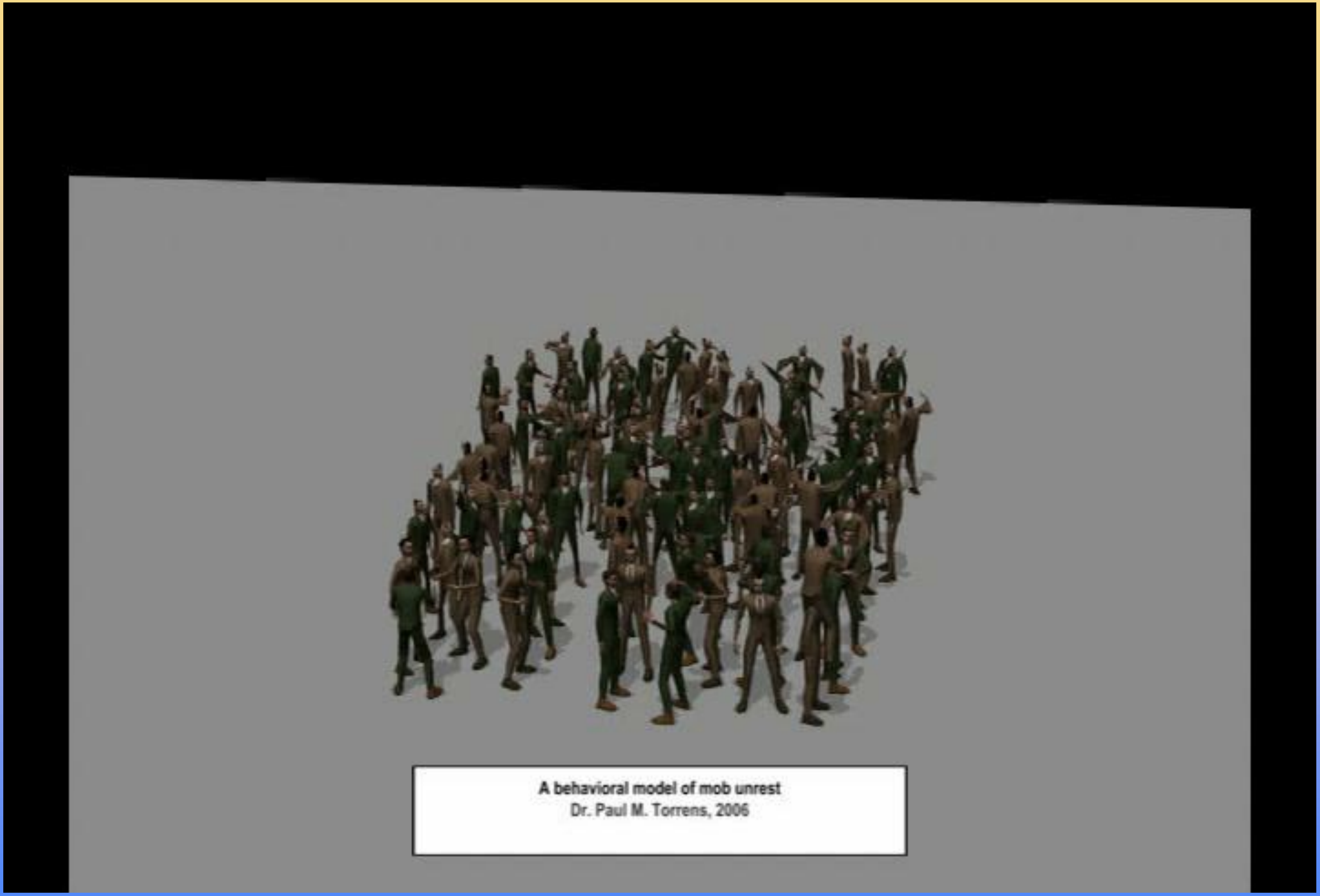
Object tags

- Tagging of objects—UPC bar-code

Pedestrian activity spaces

Agent-agent- Panic (Torrens)

Pedestrian activity spaces



Agent-agent- Mob rule (texture-, shadow-mapping)

Cities

John C. Crittenden

Hong Kong, China

43 buildings over 200 meters tall.

Metro/Urban Population: 6.9 million.

Chicago, USA

Birthplace of the modern skyscraper.

19 buildings over 200 meters tall.

Metro/Urban Population: 9.5 million.

Shanghai, China

China's biggest and most advanced city.

25 structures that are over 200 meters tall (468m downtown Oriental Pearl TV Tower).

Metro/Urban Population: 13.1 million.

New York City, USA

47 buildings over 200 meters.

Metro/Urban Population: 21.0 million.

Tokyo, Japan

Tokyo is the world's most populated city.

Metro/Urban Population: 32.0 million.

World's largest fleet of helicopters.

15 structures at over 200 meters tall.

Singapore

One of the best (urban) planned and cleanliest metropolitan cities in the world.

8 over 200 meters.

Metro/Urban Population: 3.8 million.

Toronto, Canada

7 structures in its skyline that stand at over 200 meters.

Metro/Urban Population: 5.1 million.

Kuala Lumpur, Malaysia

Metro/Urban Population: 1.5 million.

Three of the 25 tallest buildings worldwide, Petronas Towers.

Shenzhen, China

13 buildings at over 200 meters tall.

Metro/Urban Population: 4.2 million.

Seoul, South Korea

10 buildings over 200 meters tall.

Metro/Urban Population: 20.8 million.

Sao Paolo, Brazil

Only one over 200 meters tall.

Fleet of over 500 helicopters, the second largest helicopter fleet in the world.

Metro/Urban Population: 18.3 million.

Sydney, Australia

Metro/Urban Population: 4.2 million.

8 buildings over 200 meters tall.

Frankfurt, Germany

Five structures that are over 200 meters tall.

Metro/Urban Population: 4.1 million.

Dubai, United Arab Emirates

Seven structures in this city at over 200 meters.

Metro/Urban Population: 1.6 million.

Seattle, USA

4 buildings over 200 meters.

Metro/Urban Population: 3.6 million.

Pittsburgh, USA

Metro/Urban Population: 2.4 million.
Two buildings over 200 meters tall.

Guangzhou, China

Metro/Urban Population: 4.1 million.

Six structures at over 200 meters tall.

Dallas, USA

7 buildings over 200 meters.

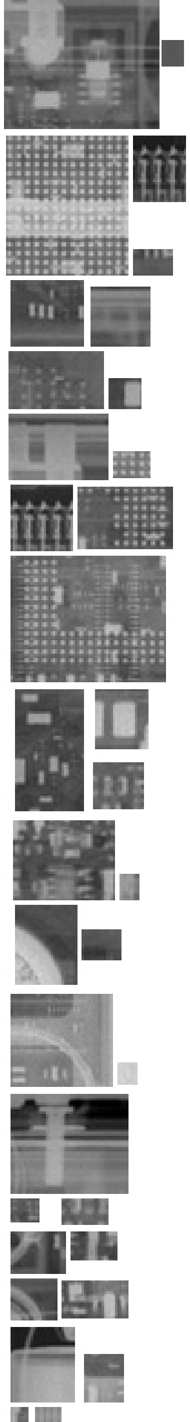
Metro/Urban Population: 5.2 million .

Reference

- http://www.diserio.com/top15-skylines.html

Computable tags

- RFID tag



Computable tags

- RFID tag

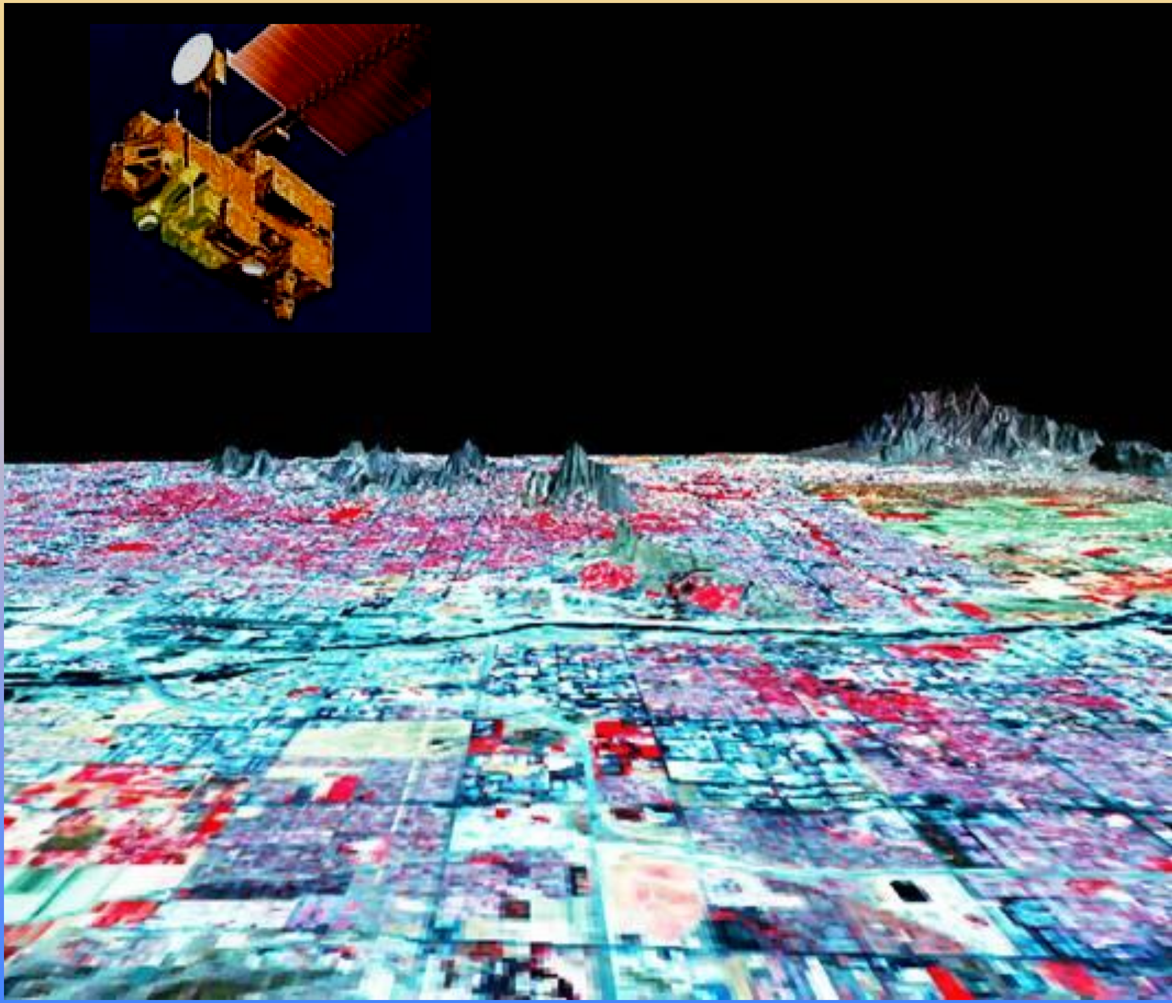
Noise – Predicted from Development Patterns and Traffic Patterns

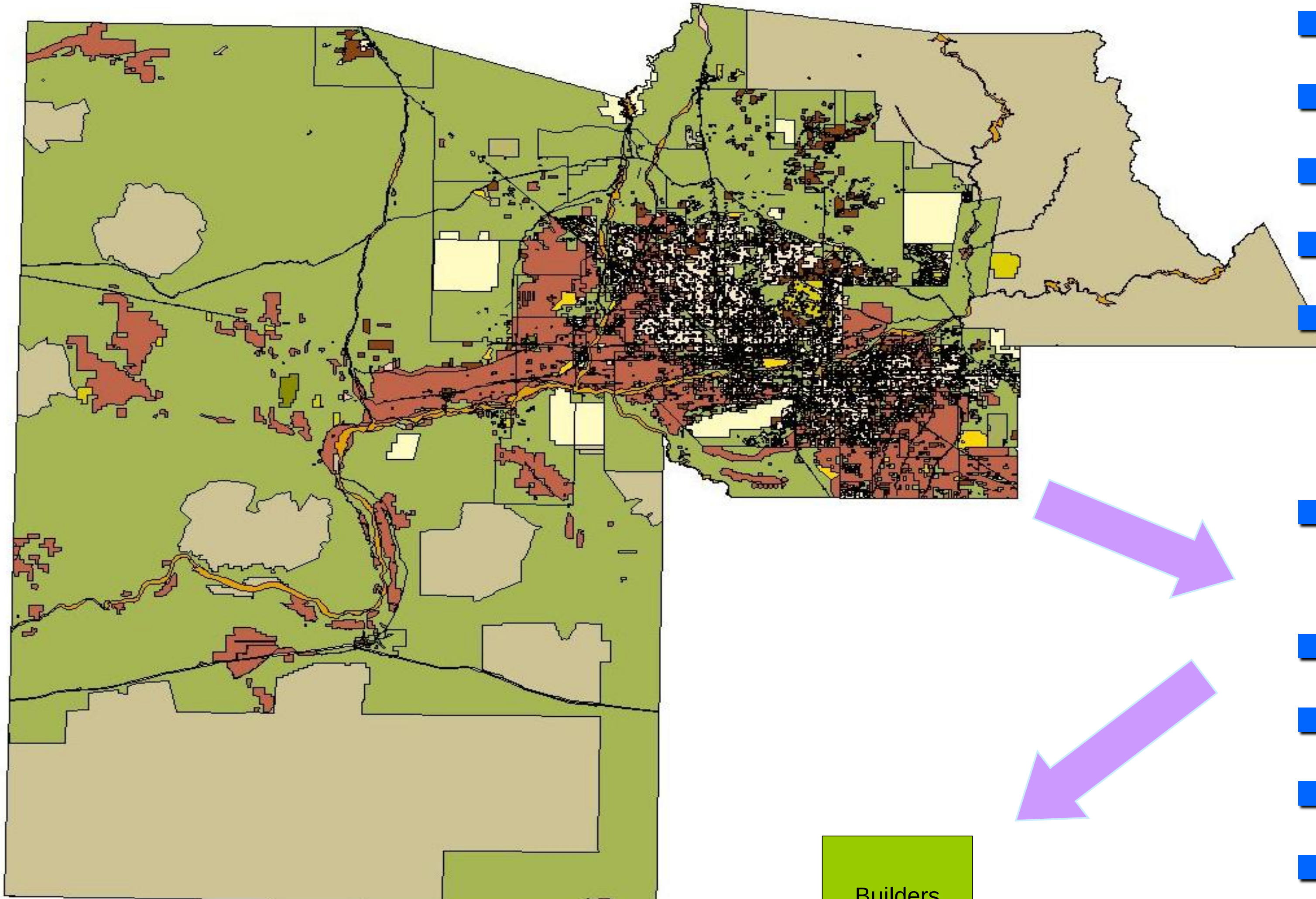
Martin Rumberg and Ariane Middel, TU Kaiserslautern

Greater Phoenix 2100 – Not Just about Rich Phoenix

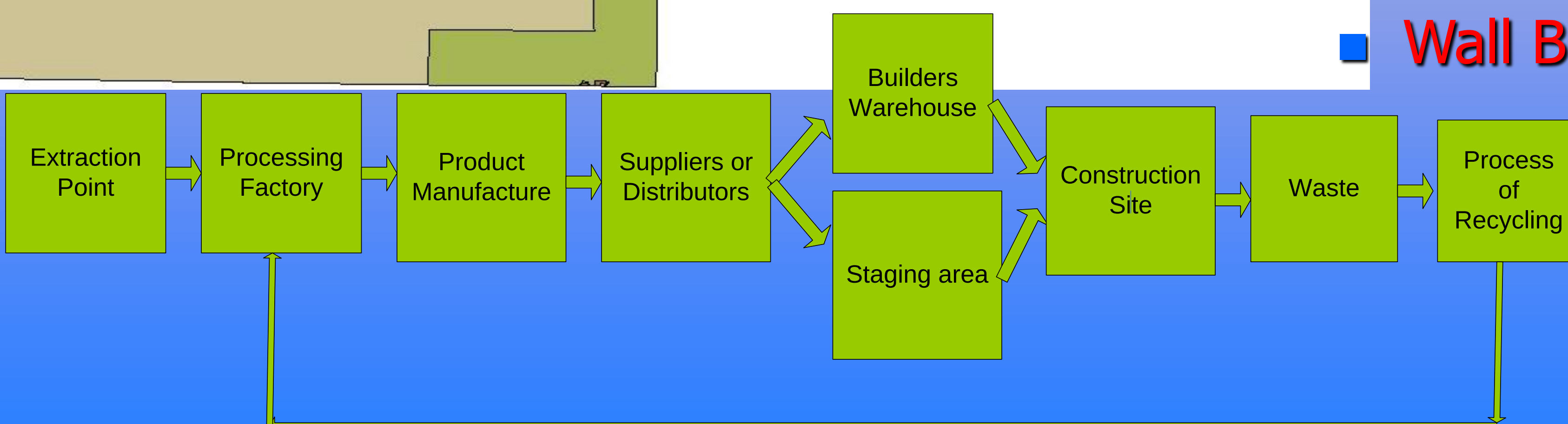
Visualization tools

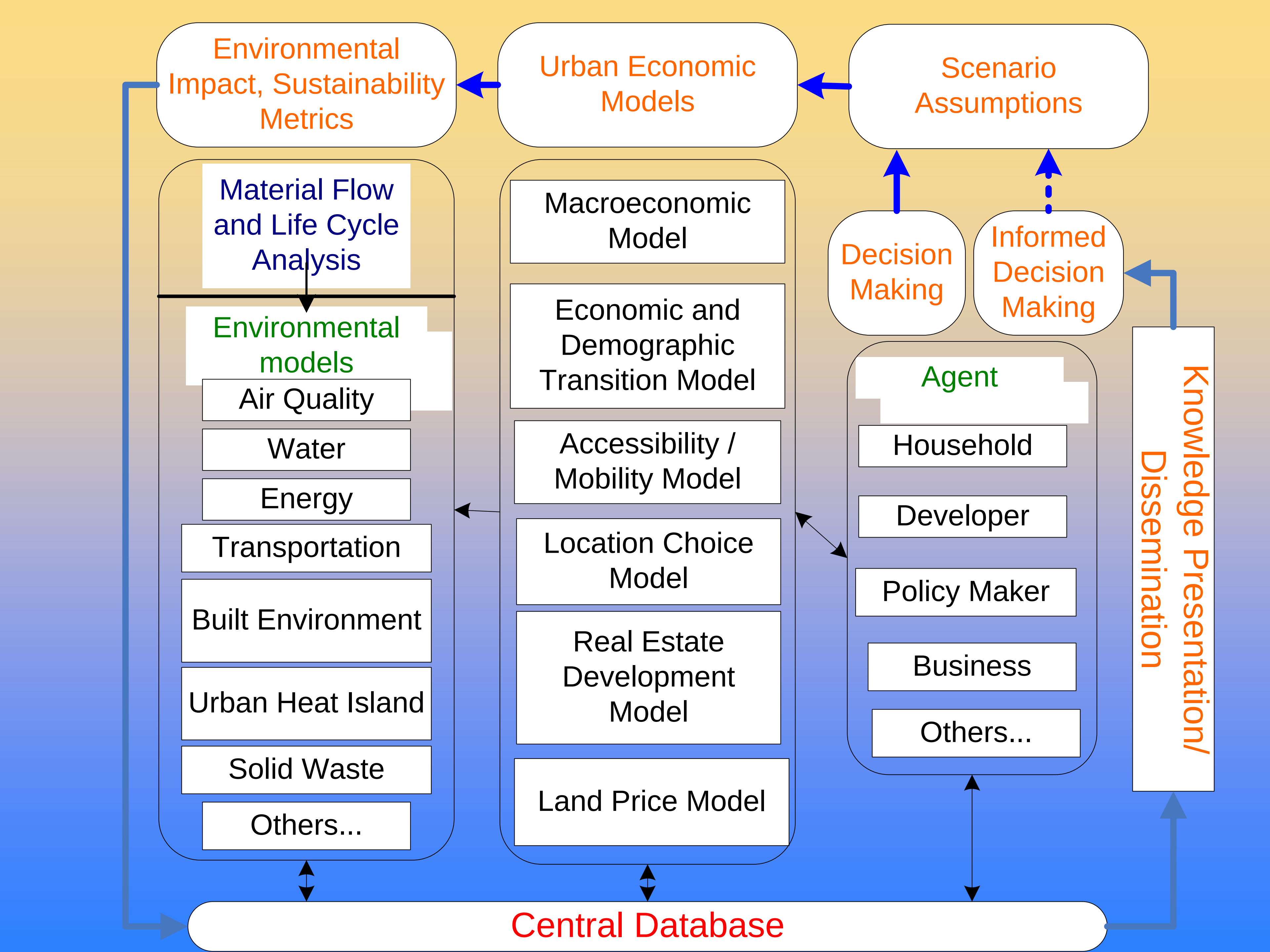
- Regional e-Atlas
- SIM Phoenix
- Decision Theater
- Urban-SAT(s)





- Energy Use
- Lumber
- Concrete
- Roof tiles
- Flooring (carpet, tile)
- Glass – (windows)
- Paint
- Steel
- Insulation
- Wall Board

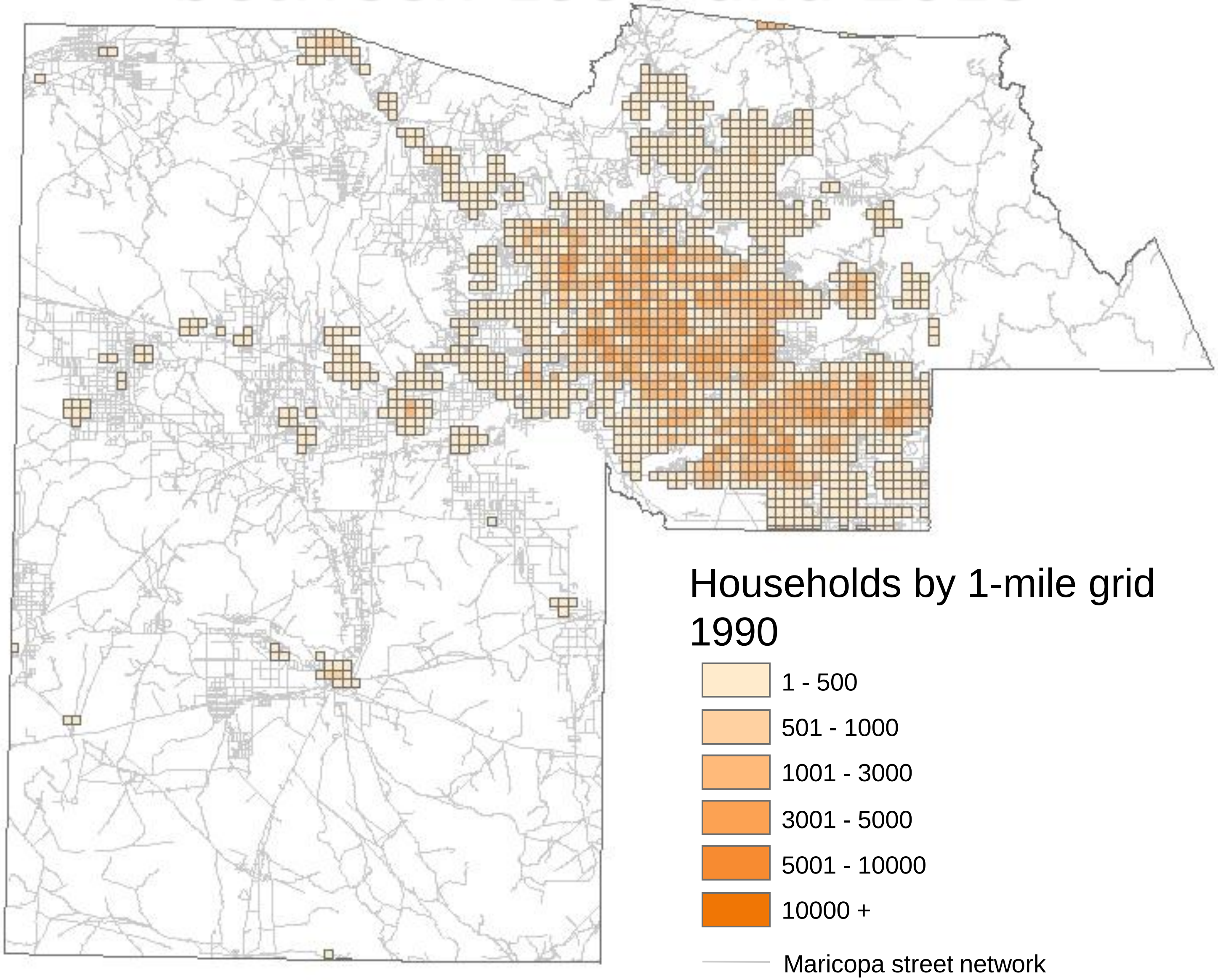



Environmental Impact, Sustainability Metrics
Urban Economic Models
Scenario Assumptions
Material Flow and Life Cycle Analysis
Environmental models
Air Quality
Water
Energy
Transportation
Built Environment
Urban Heat Island
Solid Waste
Others...
Macroeconomic Model
Economic and Demographic Transition Model
Accessibility / Mobility Model
Location Choice Model
Real Estate Development Model
Land Price Model
Decision Making
Informed Decision Making
Agent
Household
Developer
Policy Maker
Business
Others...
Knowledge Presentation/ Dissemination
Central Database

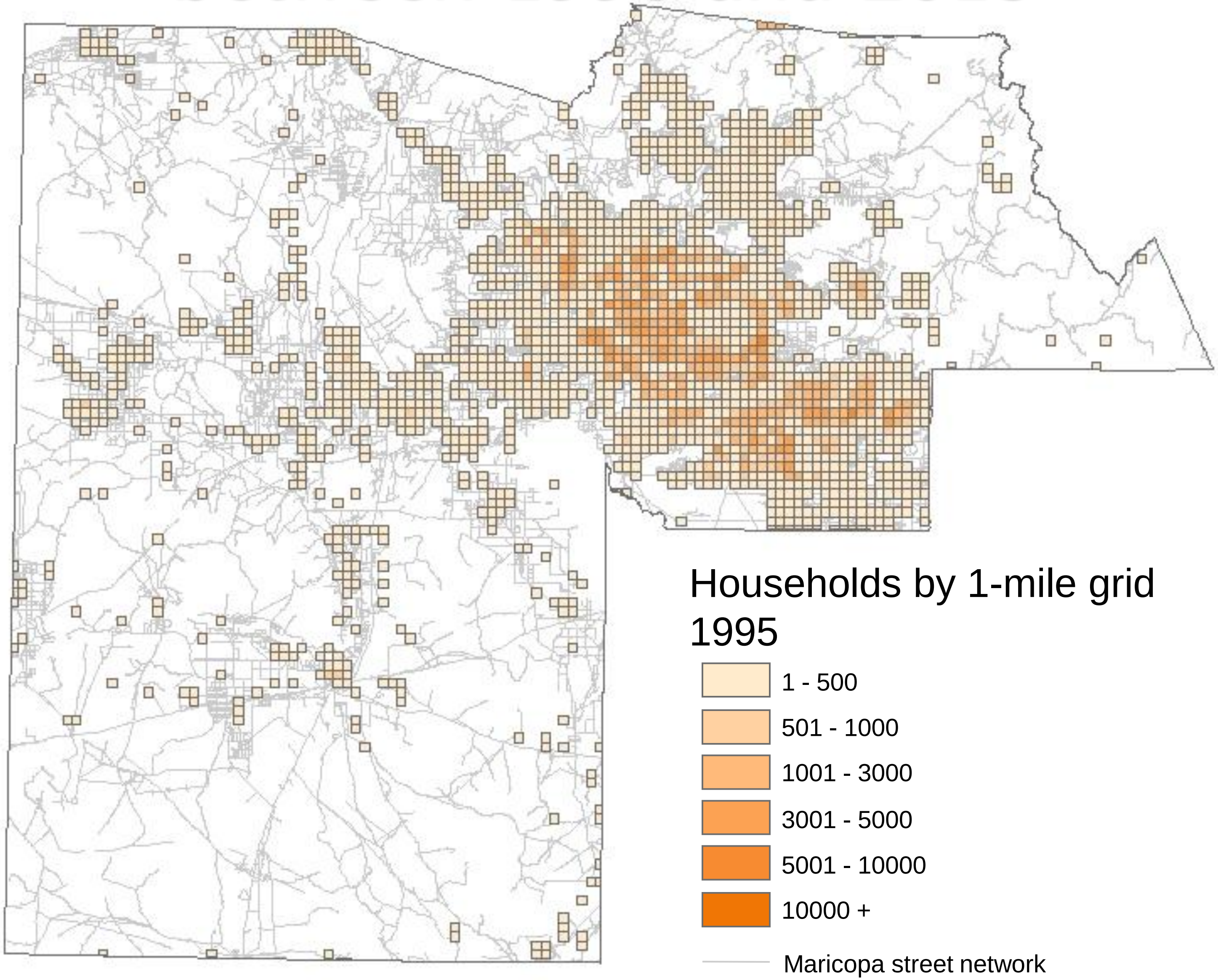
Simulating Household Location
from **1990 to 2015**
In Maricopa County

Business as usual scenario
(Guhathakurta, Konjevod, Li, Crittenden,
Joshi, Elangovan*)*

Change of household distribution between 1990 and 2015



Change of household distribution between 1990 and 2015



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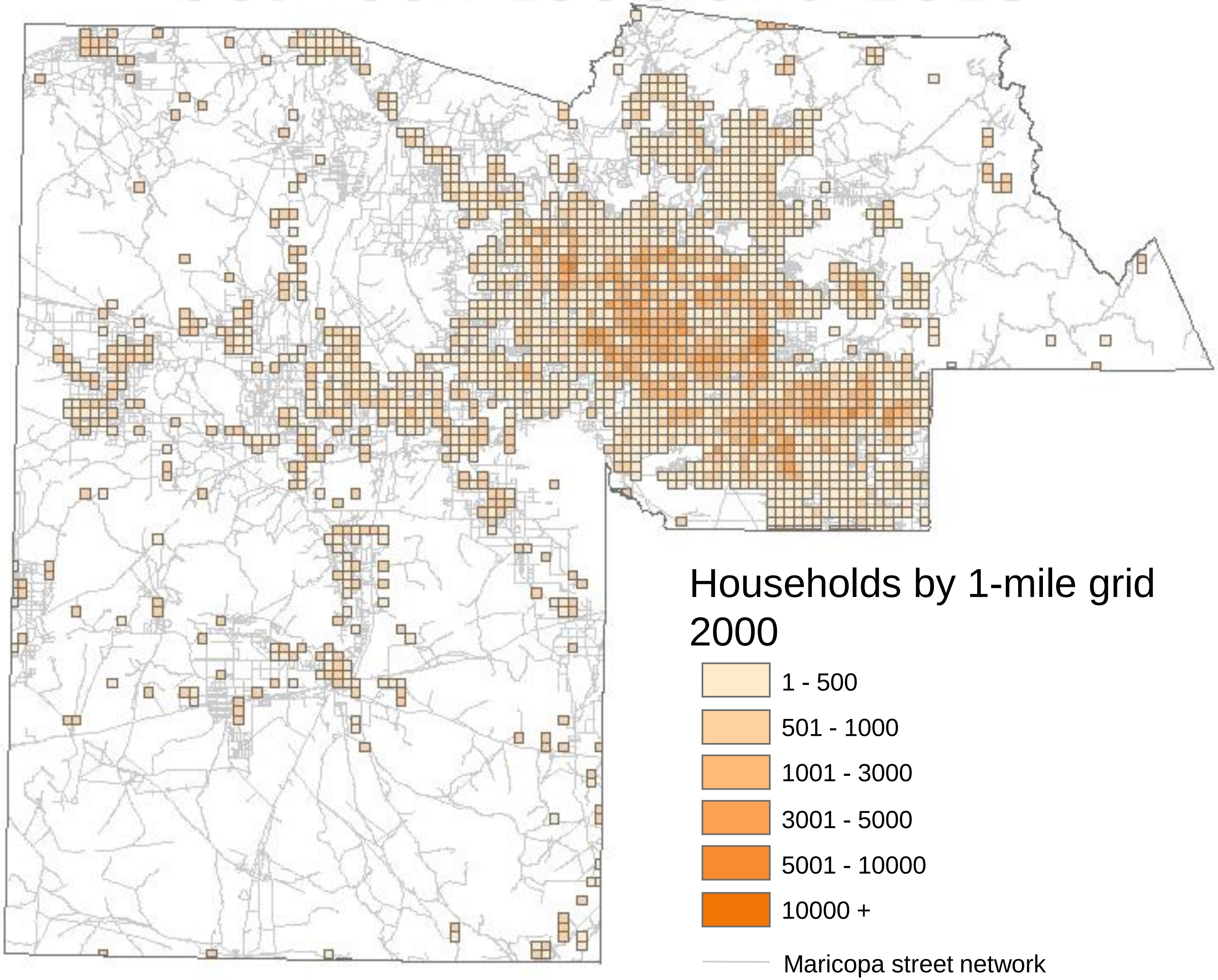

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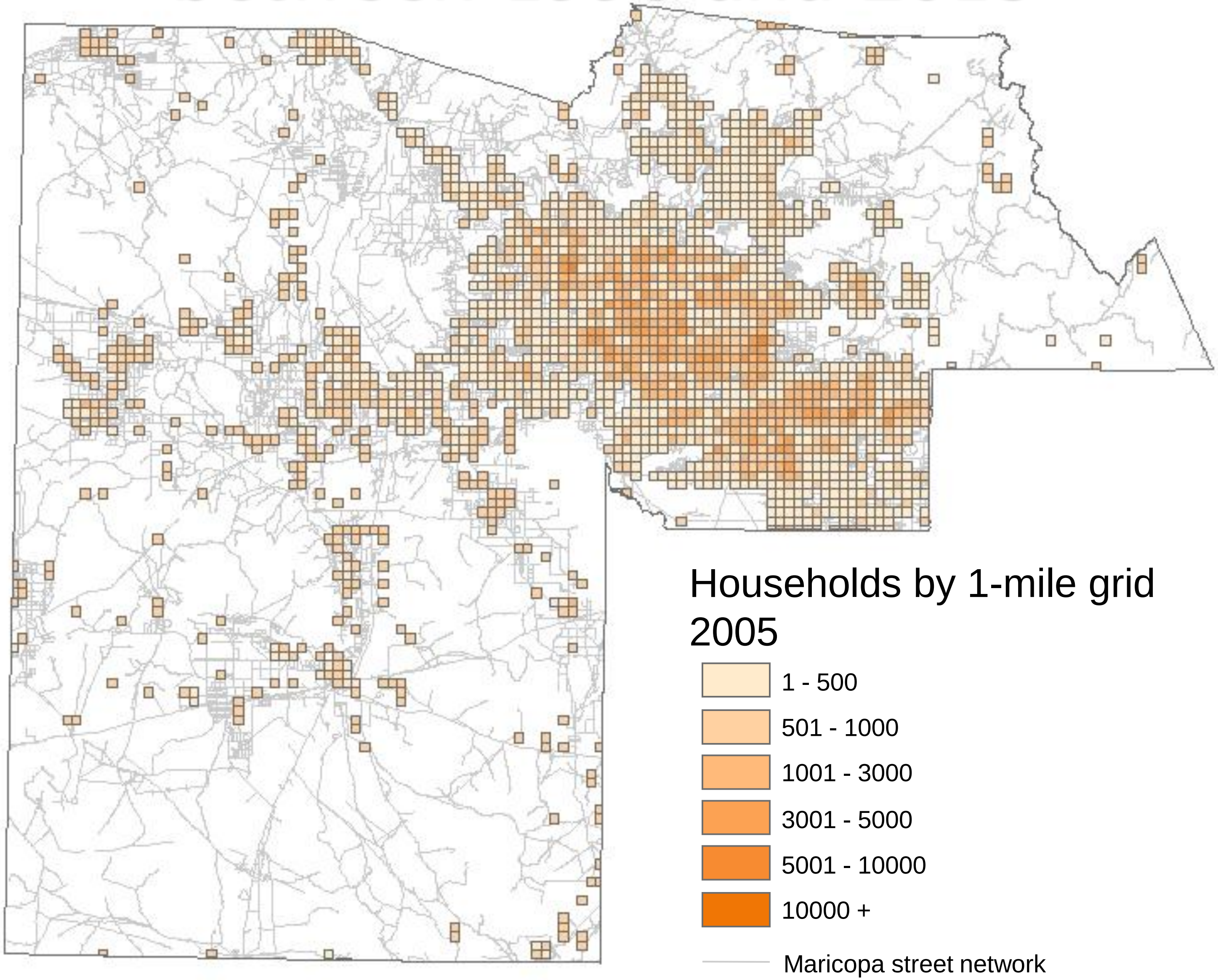
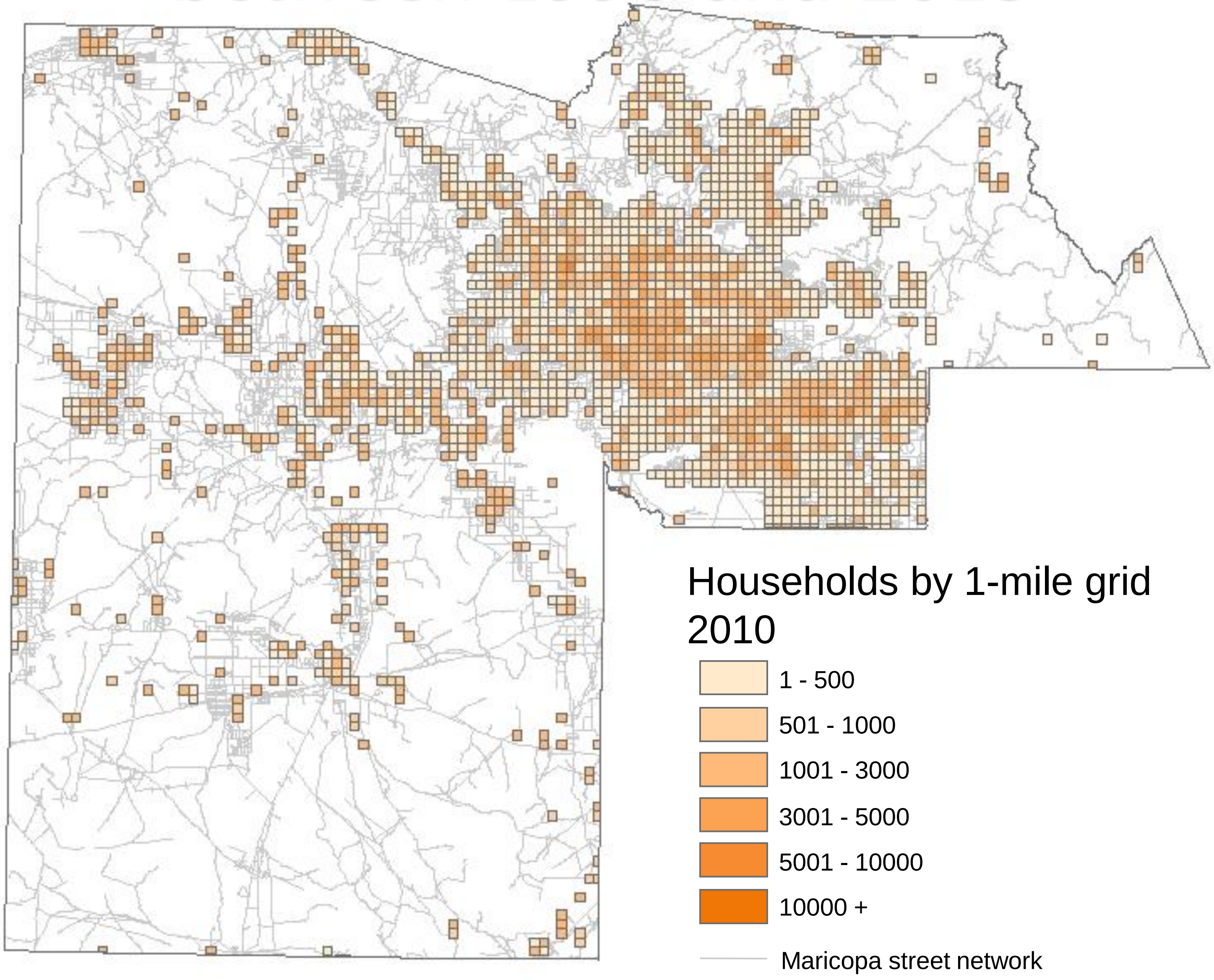
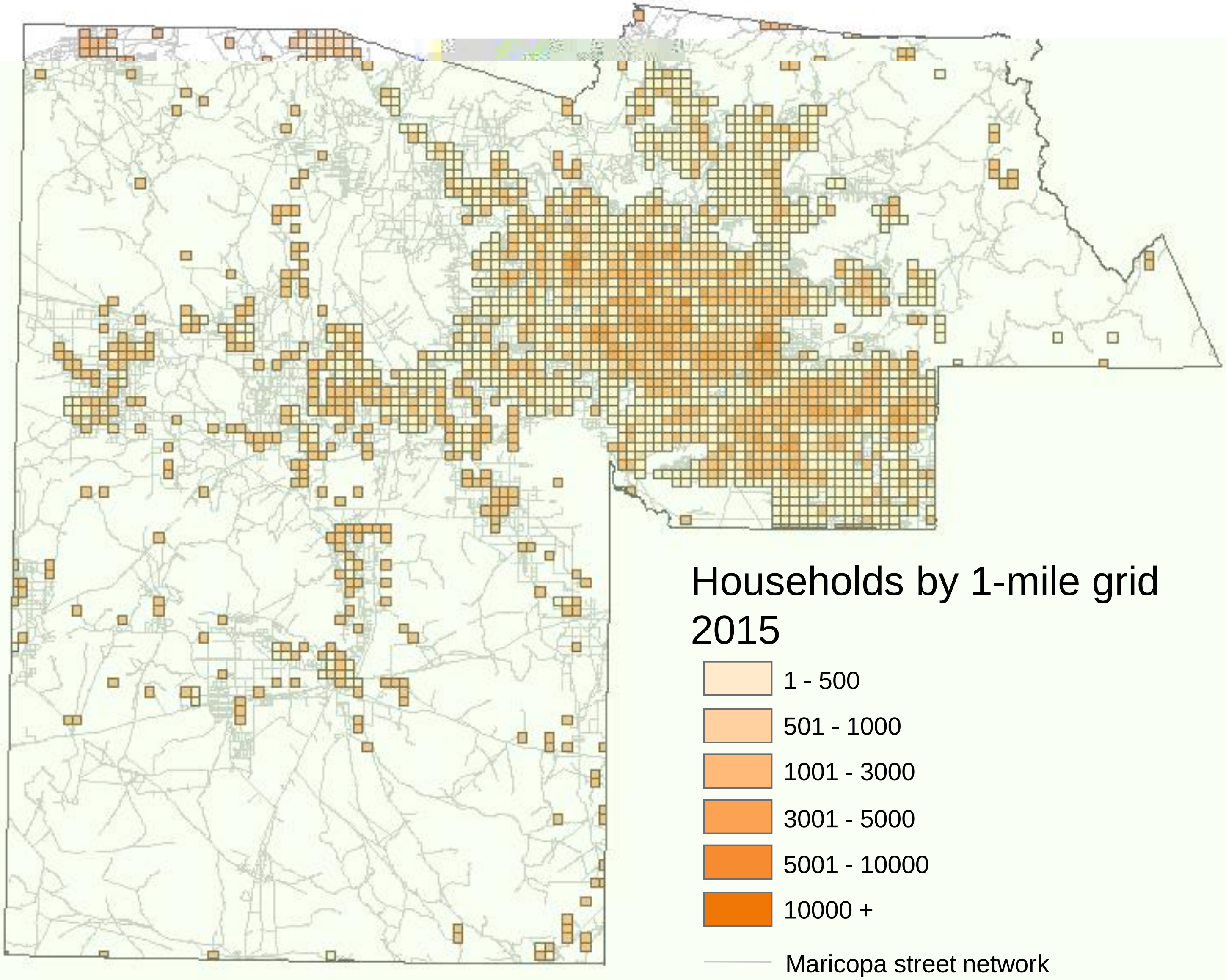


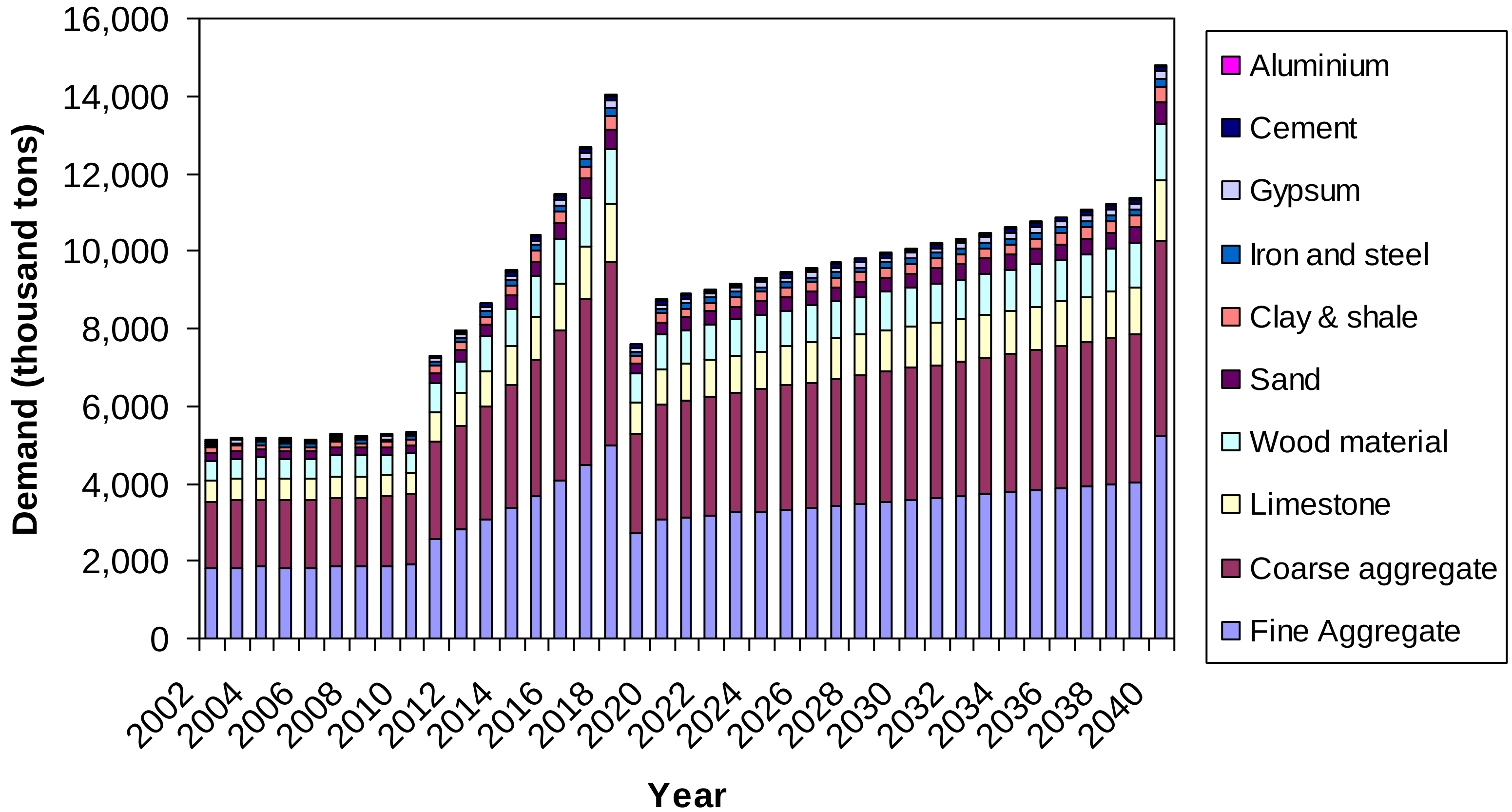
Change of household distribution between 1990 and 2015



Change of household distribution between 1990 and 2015



Annual Construction Material Demands From 2002 to 2040



Consortium of Rapidly Developing Regions

- Develop visualization tools to help policy-makers better understand implications of their decisions
- Make science and engineering results more accessible
- Promote regional and long-term perspectives
- Partner with businesses and state agencies

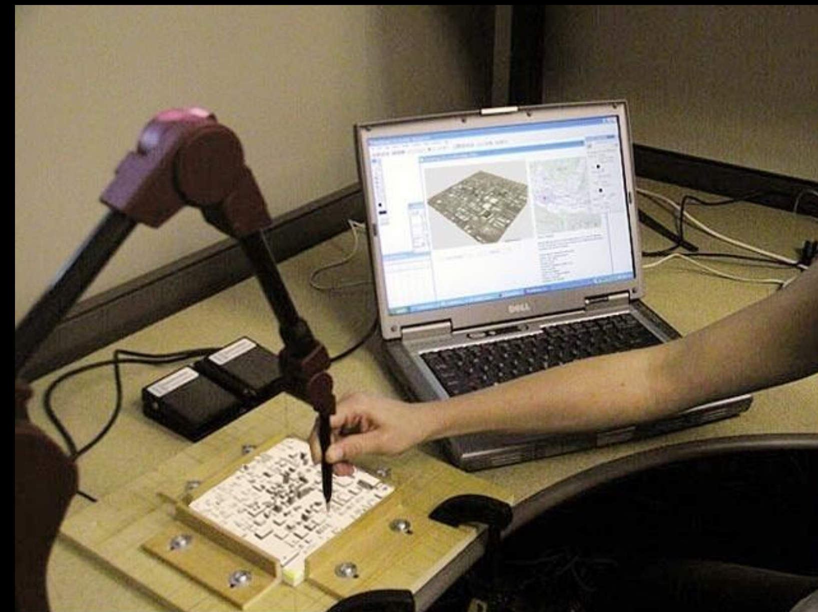
- Shenzhen, China
- 13 buildings at over 200 meters tall.
- Metro/Urban Population: 4.2 million.

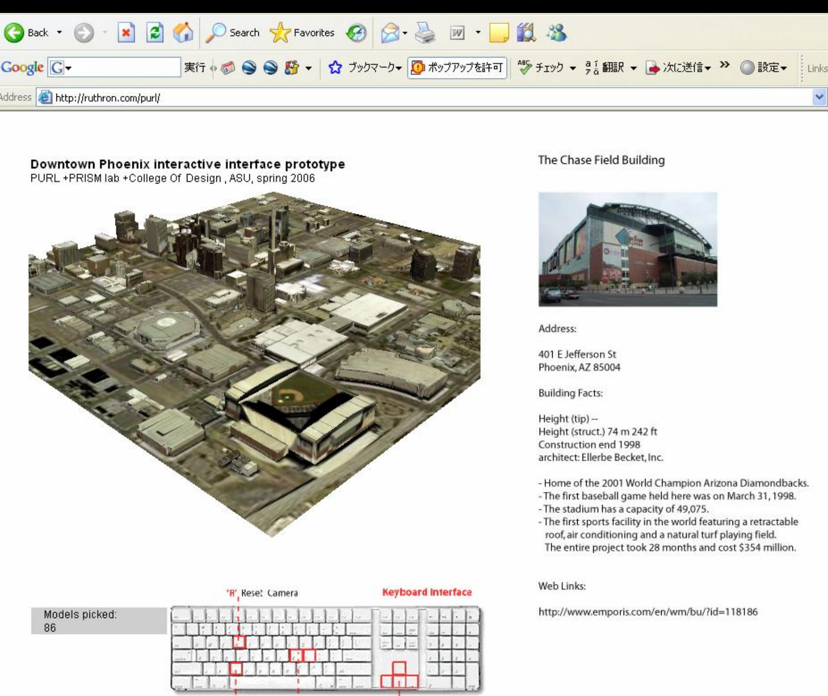
Digital Phoenix:

3D modeling…

Digital Phoenix:

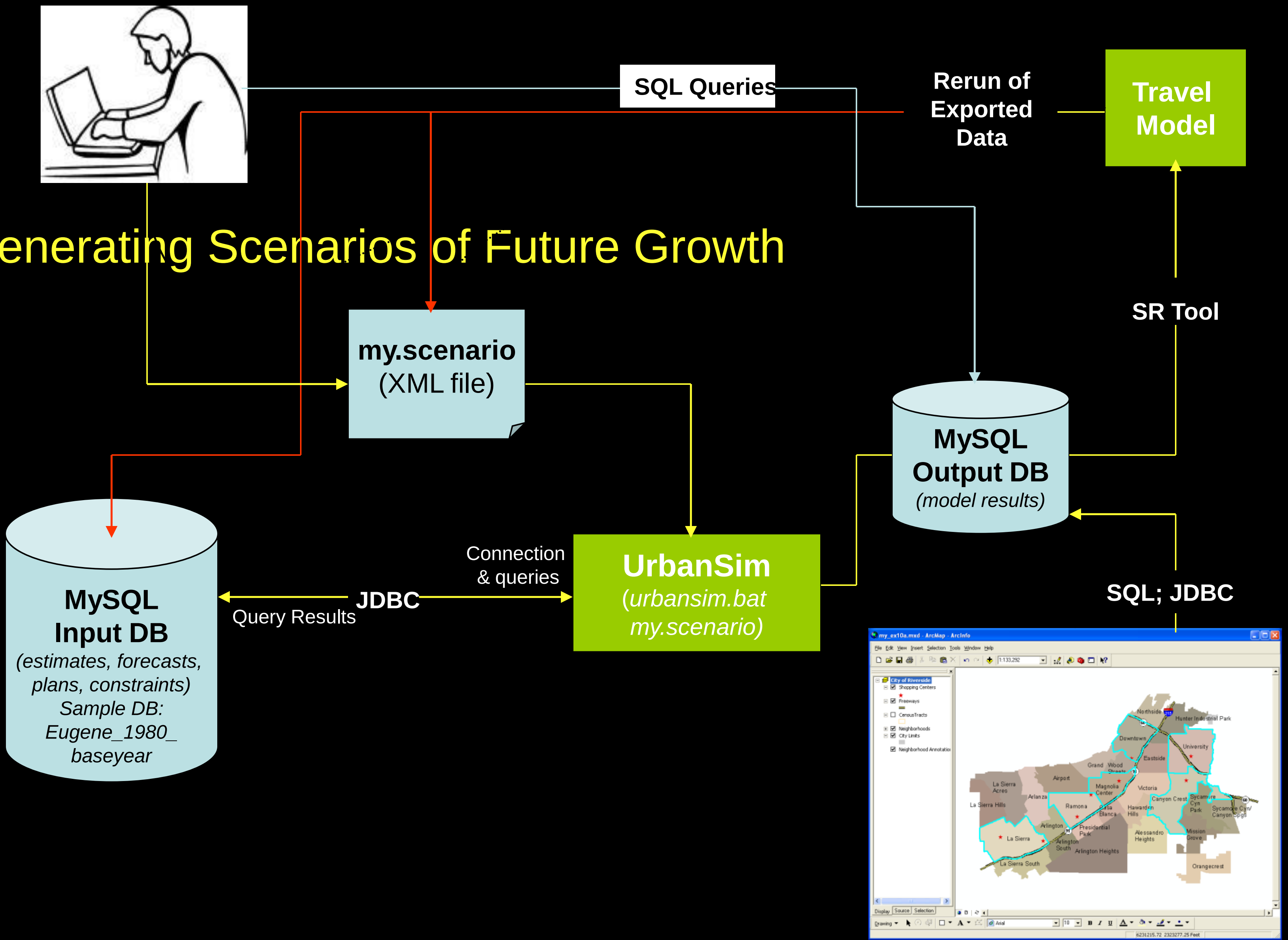
Partners…



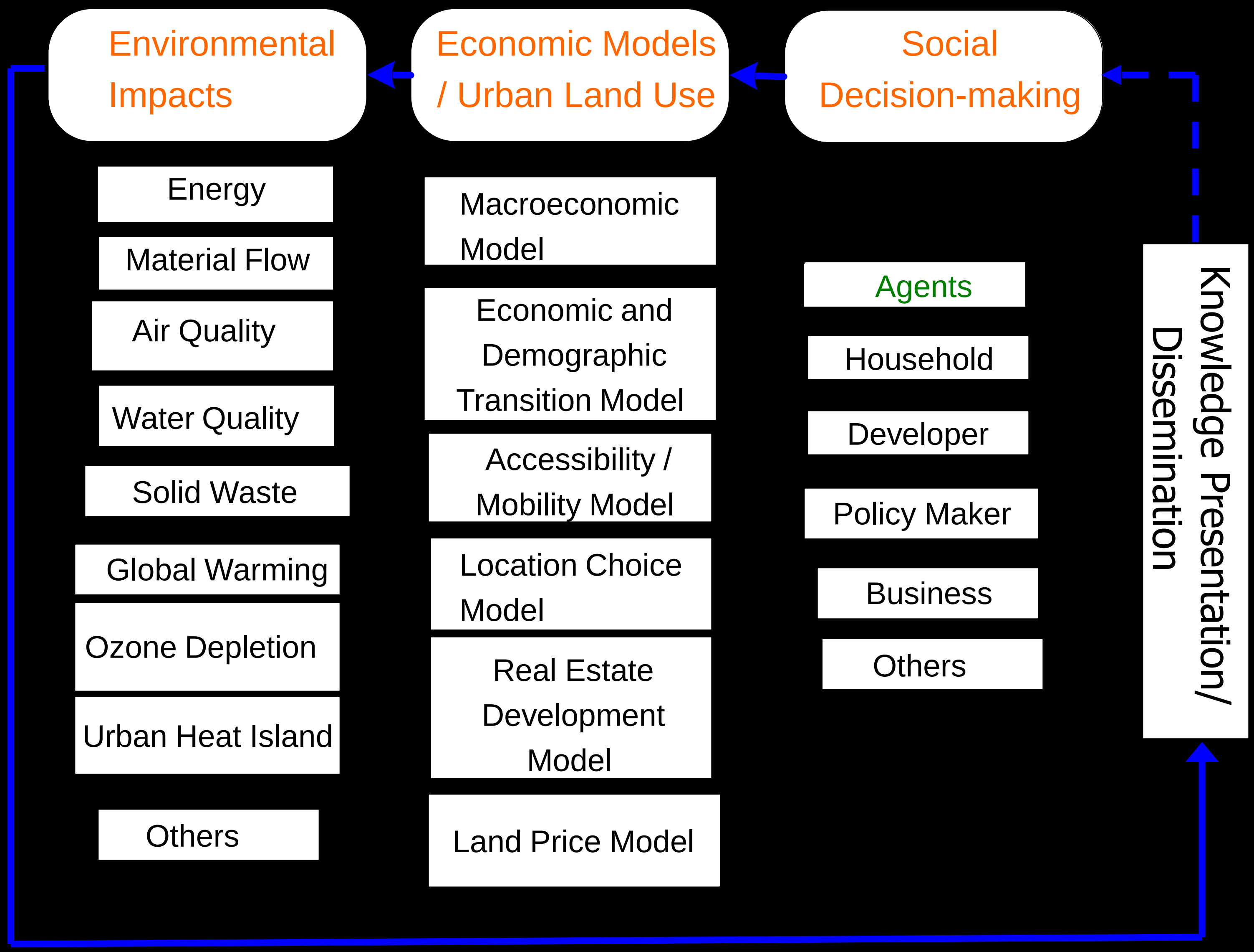


Digital Phoenix:

Generating Scenarios of Future Growth



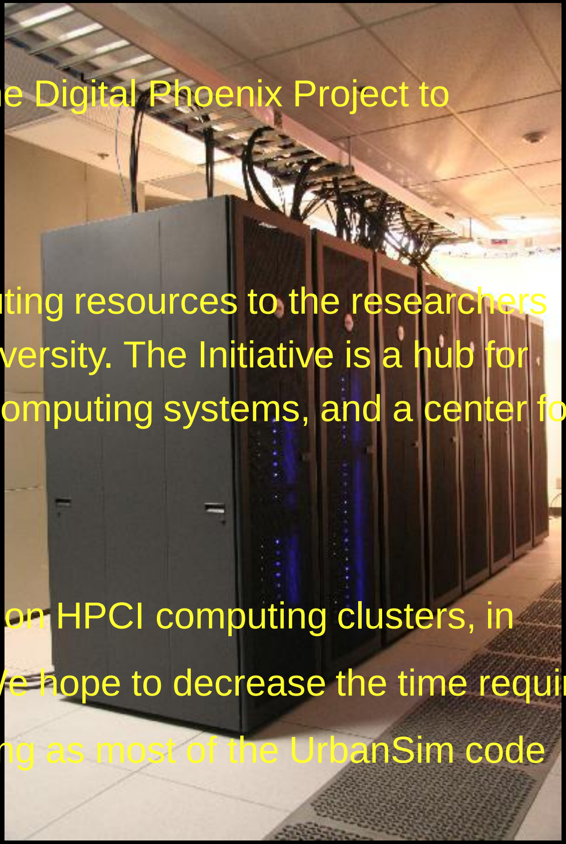
Framework of simulation models



Digital Phoenix:

Parallel UrbanSim

Steffen Eikenberry, Student, Fulton HPCI



The Fulton High Performance Computing Initiative (HPCI) is working with the Digital Phoenix Project to accelerate the performance of UrbanSim through parallel processing.

Overview of the HPCI

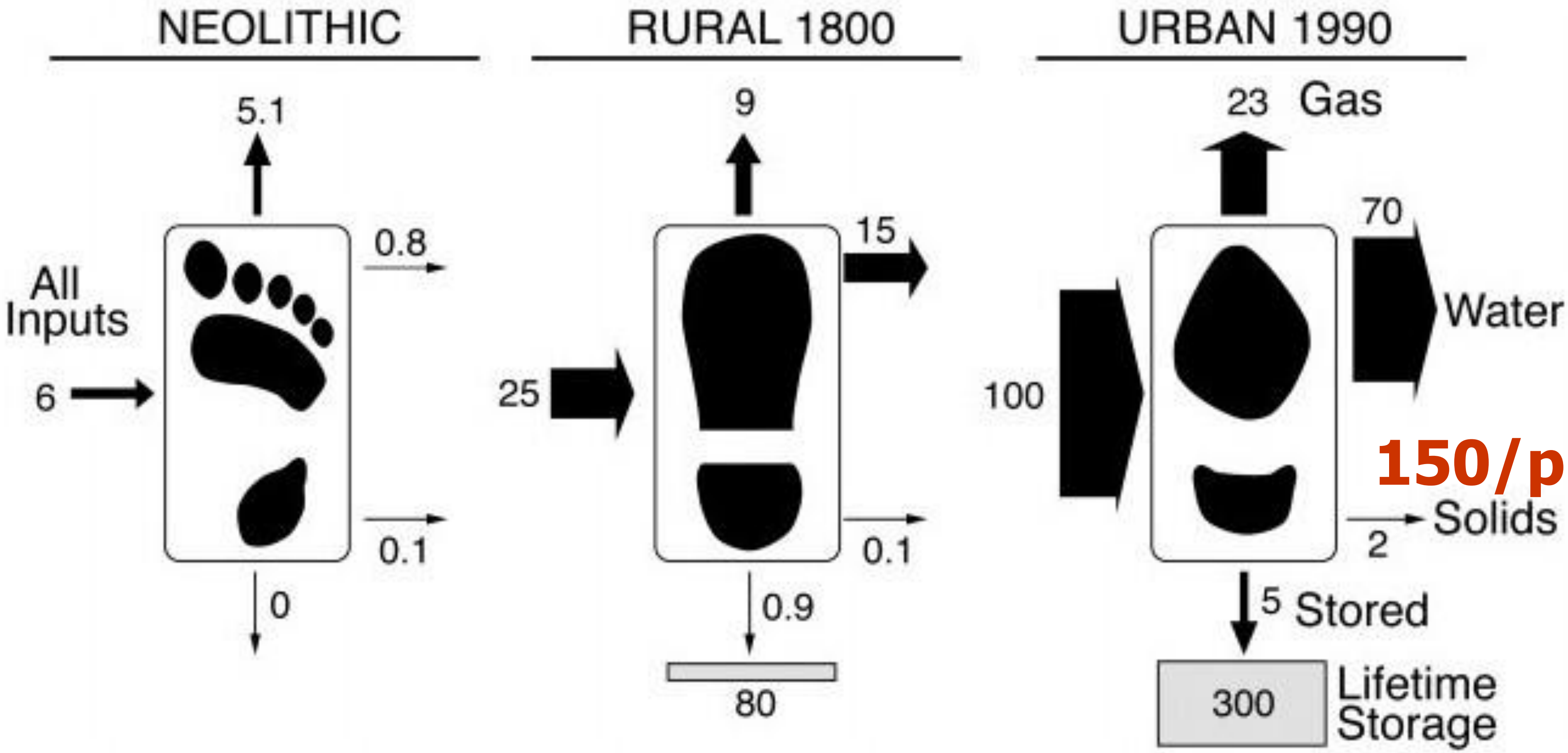
The Fulton High Performance Computing Initiative offers world class computing resources to the researchers and students in the Ira A. Fulton School of Engineering at Arizona State University. The Initiative is a hub for research in computing, collaborative research in the application of parallel computing systems, and a center for education in high performance computing systems.

HPCI and Digital Phoenix

Our goal is to modify the UrbanSim program so that it can be run in parallel on HPCI computing clusters, in order to enable real-time visualization and accelerate research progress. We hope to decrease the time required to run UrbanSim by at least an order of magnitude.Early results are promising as most of the UrbanSim code has been parallelized, resulting in a significant decrease in runtime.

ASU Ira A. Fulton school of engineering
ARIZONA STATE UNIVERSITY
High Performance Computing Initiative

Regional/ Global Impacts: Urban Metabolism – Energy and Materials are Transformed into Durable Infrastructure and Waste

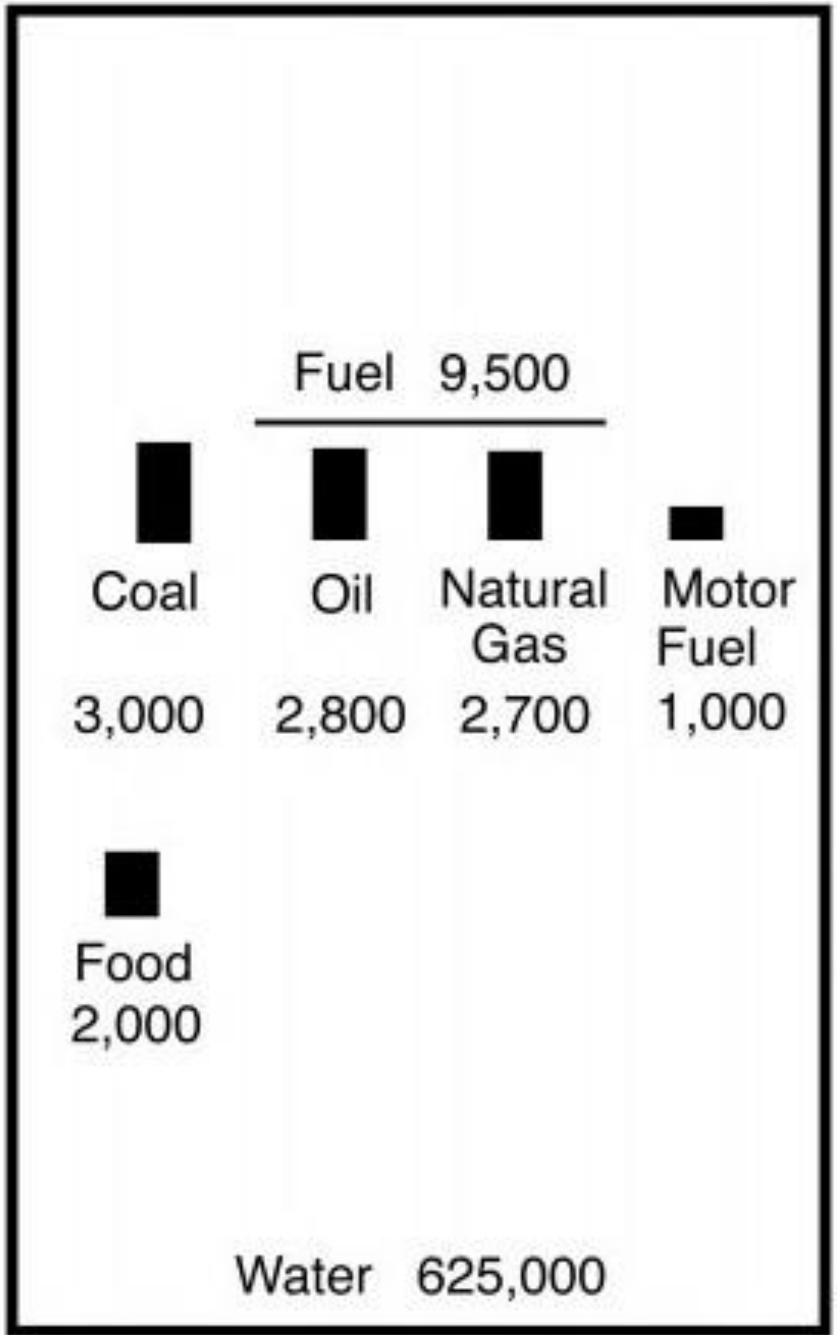


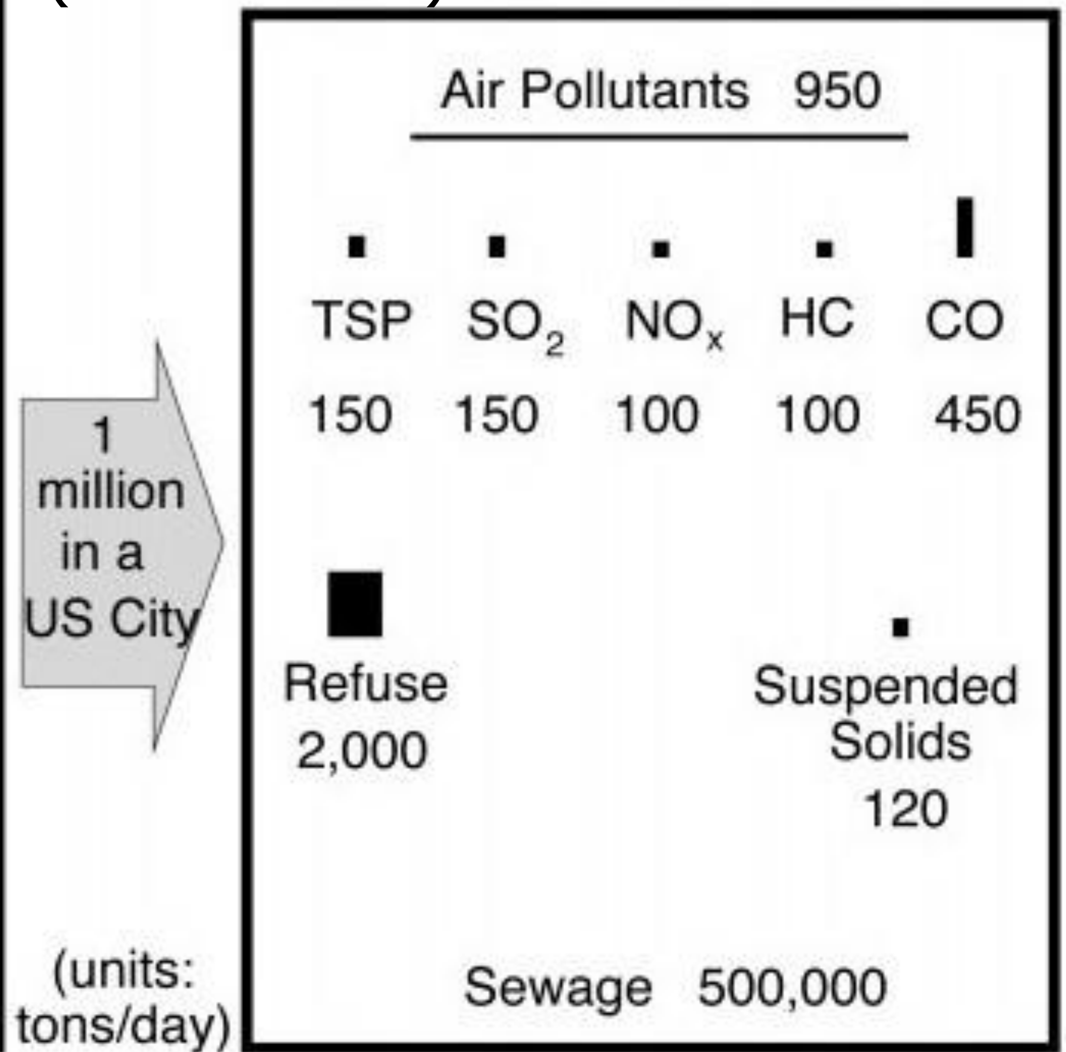
150/p

All units are tons per year per individual. Life time storage includes infrastructure and artifacts. (Decker et al.) Still increasing inputs by 2.5%/ year.

Urban Metabolism

All units are tons per day for a city of 1 million residents. Rectangle size is proportional to the mass. Suspended Solids are in Sewage. (Decker et al.)





Evolution of EES Education

- Conventional and Toxic Pollution Transport, Impact, Mitigation and Risk Reduction
- We need is to focus on systems level activities.
- This includes: Industrial Ecology, Earth Systems Engineering, Engineering the Anthrosphere to Live within the Means of Nature (or our alteration of it).
- Start by examining material and energy flow and its consequences in urban systems (e.g., toxic releases, conservation, environmental disturbances, etc.)

Core Team Members - I would like to express my thanks to the following ASU colleagues for their contributions to this presentation:

- Braden Allenby, Industrial Ecology, Civil and Environmental Engineering
- Yongsheng Chen, Industrial Ecology, Civil and Environmental Engineering
- Joe Fernando, Air Quality Modeling, Mechanical and Aerospace Eng.
- Dave Guston, Consortium for Science, Policy and Outcomes, Department of Political Science
- Nancy Grim, Ecology, School of Life Sciences
- Subhrajit Guhathakurta, Urban Planning, School of Planning and Landscape Architecture
- Goran Konjevod, Transportation Modeling, Computer Science & Engineering
- Ke Li, Cyber Infrastructure, Agent Based Modeling of Decision Making, Civil and Environmental Engineering
- Charles Perrings, Environmental Resource Economist, School of Human Evolution and Social Change
- Daniel Sarewitz, Consortium for Science, Policy and Outcomes, College of Liberal Arts and Sciences
- Anil Sawhney, Material Flow Analysis at Construction Sites, Del Webb School of Construction
- Kerry Smith (NAS member), Environmental Resource Economist, WP Carey School of Business
- Paul Torrens, Modeling of Urban Change and Human Behavior, Dept. of Geography
- Joe Zehnder, Urban Heat Island, Dept. of Geography and Mathematics,

Additional Collaborators - I would like to express my thanks to the following ASU colleagues for their contributions to this presentation:

- Phil Christensen, Department of Geological Sciences
- Jonathan Fink, Professor and Vice Provost for Research and Economic Affairs, Department of Geological SciencesJay Golden, Global Institute of Sustainability David Pijawka, School of Planning
- Ray Quay, the City of Phoenix Planning Department
- Chuck Redman, Director of Global Institute of Sustainability
- Jianguo (Jingle) Wu, School of Life Sciences

Student Investigators - I would like to express my thanks to the following ASU students for their contributions to this presentation:

- Susanne Grossman Clarke, Urban Heat Island, Dept. of Geography and Mathmatics
- Yu-Jin Choi, Air Quality Modeling, Mechanical and Aerospace Eng.
- Miles Costanza, Daniel Gerrity, Ramzy Kahhat, Peng Zhang, Fariyah, Sharif, Industrial Ecology, Material Flow Analysis, Civil and Environmental Engineering
- Thanigaivelu Elangovan, Computer Science and Engineering
- Himanshu Joshi, School of Planning and Landscape Architecture.
- Sonja Winters, Del Webb School of Construction