Sustainable Infrastructures for Energy and Water Supply (SINEWS)

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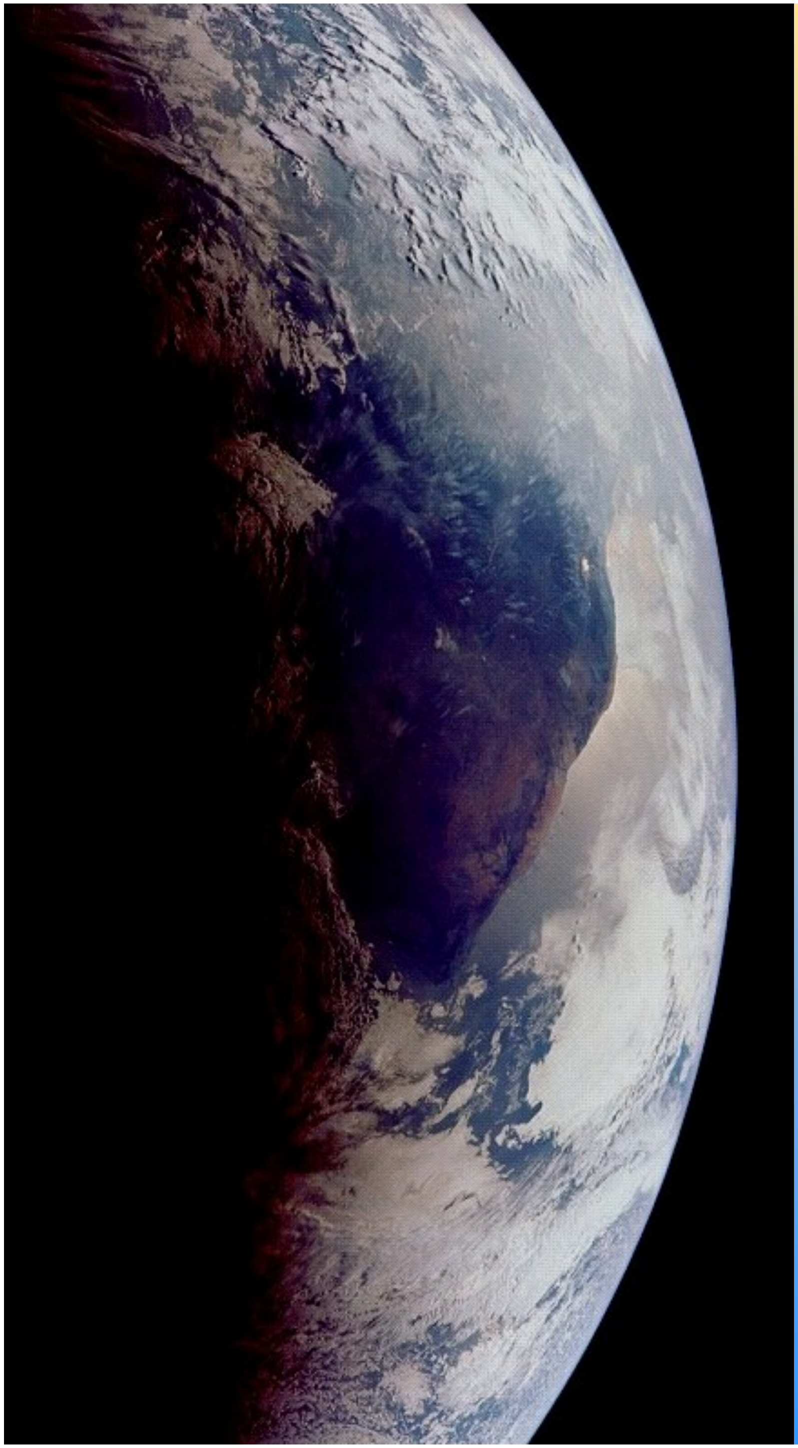
Projects under SINEWS

- **SINEWS**
  - Physical Environment
    - **Land use scenarios and forecasting**
      - Steve French (ATL)
      - Ke Li (PHX)
  - Socio-economic Environment
    - **Hedonic price estimation for infrastructure reliability**
      - Charles Perrings
      - Doug Noonan
    - **Land use and policy**
      - Marilyn Brown
  - Water Infrastructure
    - **Life cycle assessment of centralized and decentralized water/wastewater systems**
      - John C. Crittenden
      - Eric Williams
    - **Reliability of water distribution system**
      - Sam Ariaratnam
    - **Water Resources**
      - Aris Georgakakos
    - **Resiliency of Civil Infrastructure**
      - Reginald Desroches
  - Energy Infrastructure
    - **Life cycle assessment of centralized and decentralized energy production system**
      - George Karady
      - Miroslav Begovic
      - Eric Williams
    - **Decentralized energy production and electrified transportation**
      - Bert Bras



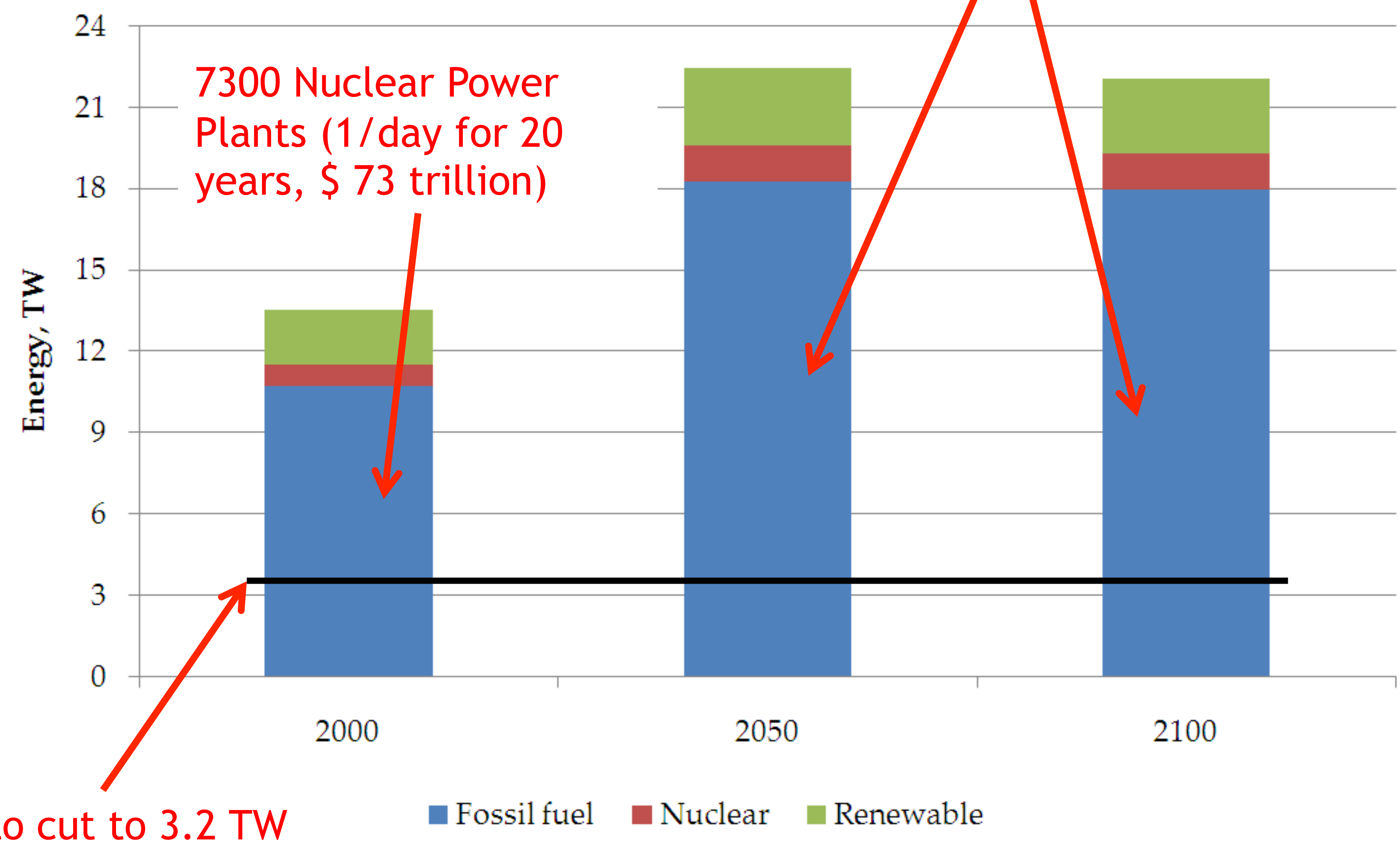
Outline

- **What is the Gigaton Problem?**
- **Material and Energy Challenges**
- **Urban Systems**
- **Concluding Remarks**

CO_2 Target – 70% Reduction from 2000 emissions 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)

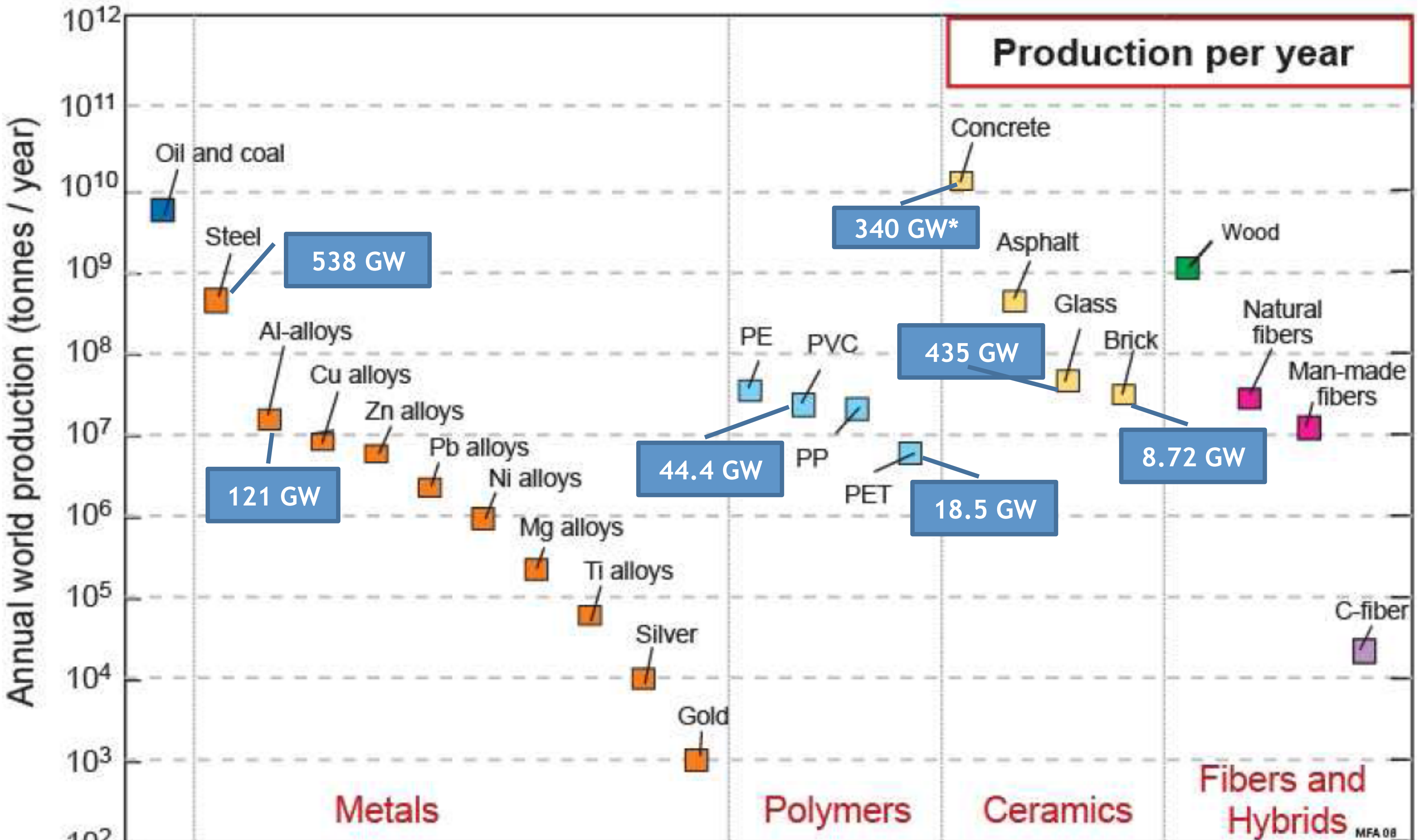


Need to cut to 3.2 TW
to Achieve 70%
Reduction

Decision Time – Climate Change

- We can only have 3.2 trillion watts of carbon based energy.
- 500 watts per person for 6.5 billion people
- 12,000 W/ person US
- 5,000 W/ person France
- 100 w - Mali
- Human Life = 100 w
- Replace 7.3 billion tons of carbon based energy with renewable energy
- 1 Gt C = 100 billion dollars @ $100/ton
- .73 Trillion Dollars for 7.3 billion tons of carbon

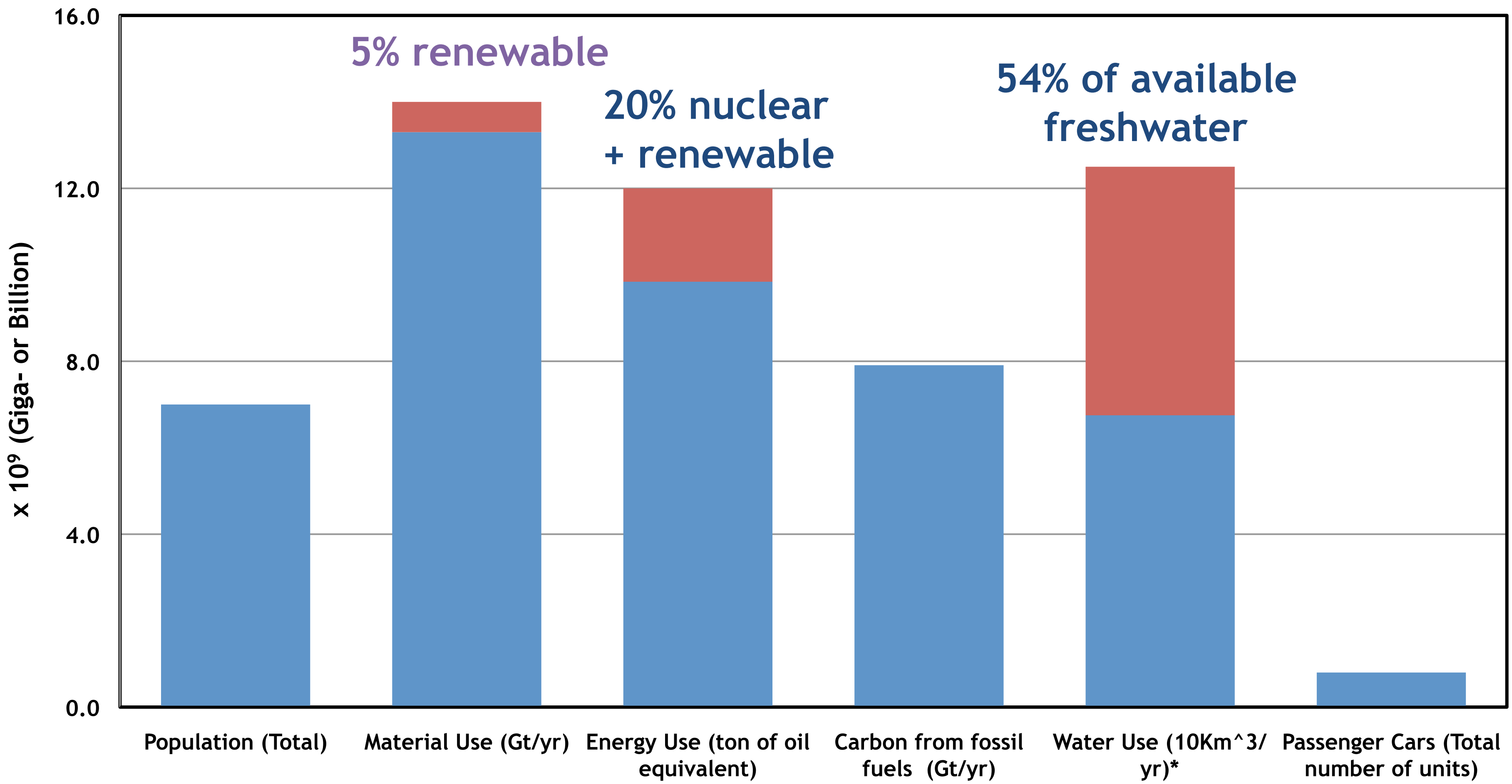
Resource Consumption for Material Production



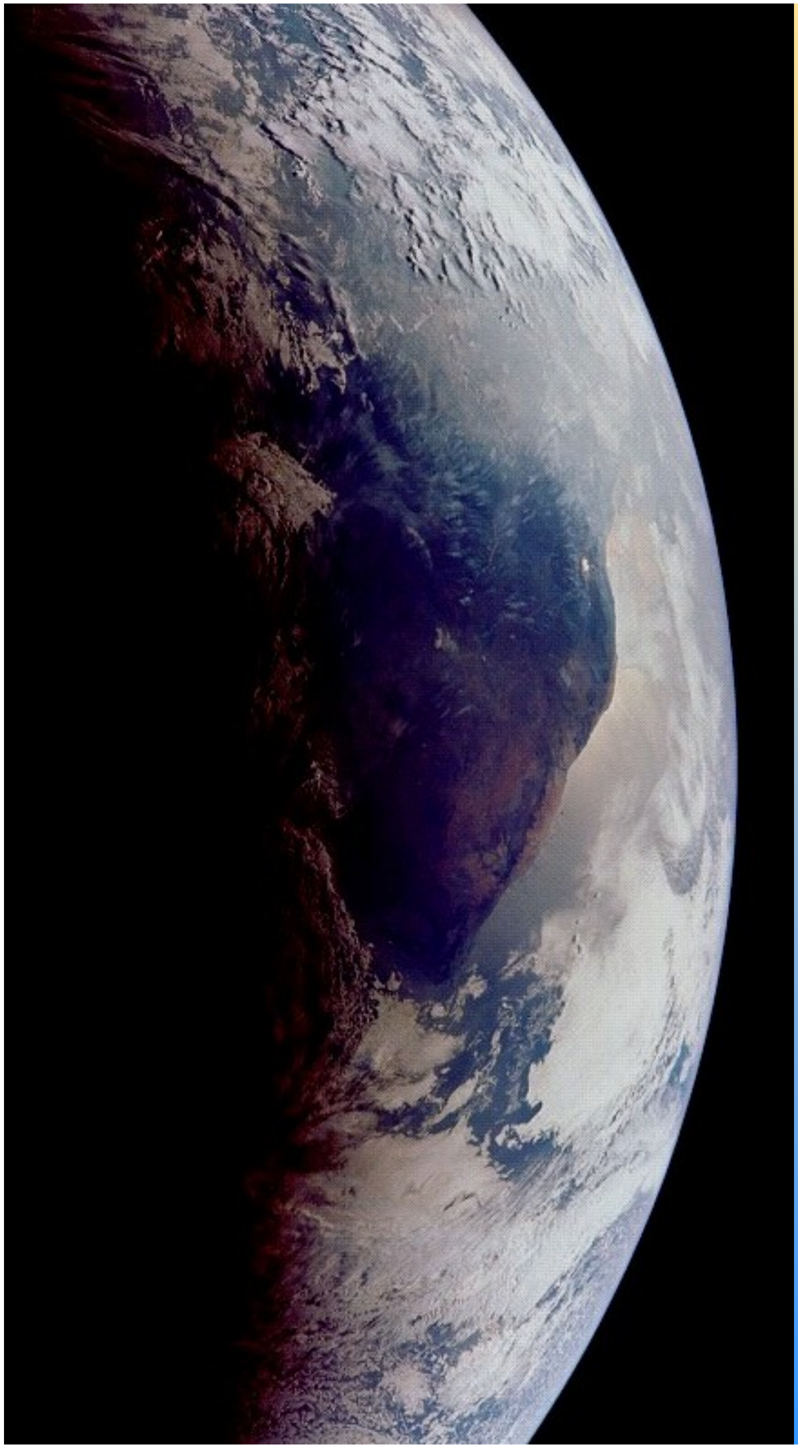
Credit: Mike Ashby

•Ratio based on mix design for 30 MPa compressive strength at 28 days (http://www.ctre.iastate.edu/pubs/sustainable/strublesustainable.pdf)

Gigaton Problems Require Gigaton Solutions! Infrastructure Ecology



Ming Xu, John Crittenden, Yongsheng Chen, Valerie M. Thomas, Douglas Noonan, Reginald DesRoches, Marilyn Brown, Steve French, Env. Sci and Tech. June 2010



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Fundamental Question for Solving the Gigaton Problems

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

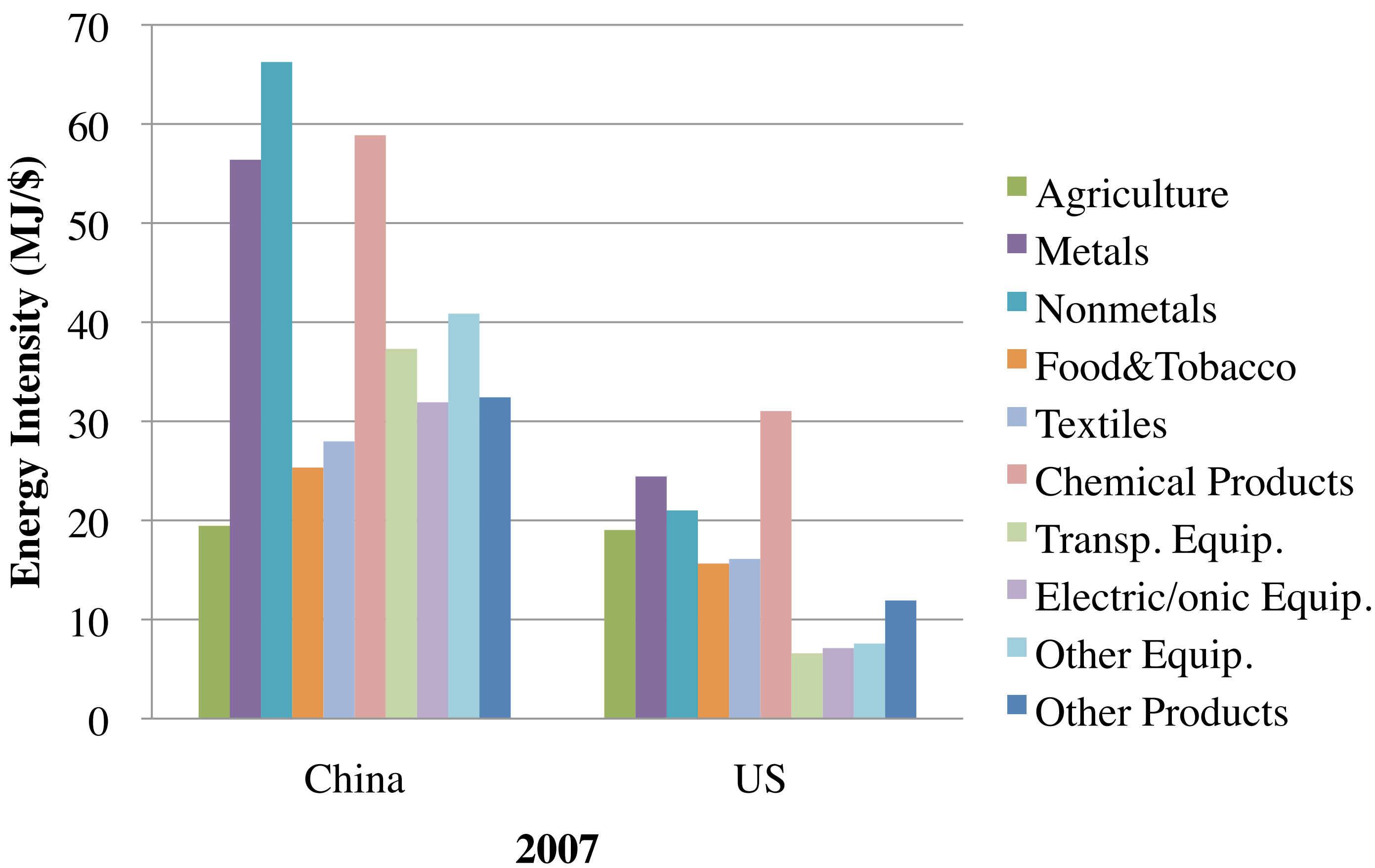
Energy

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 of China and the U.S. in 2007



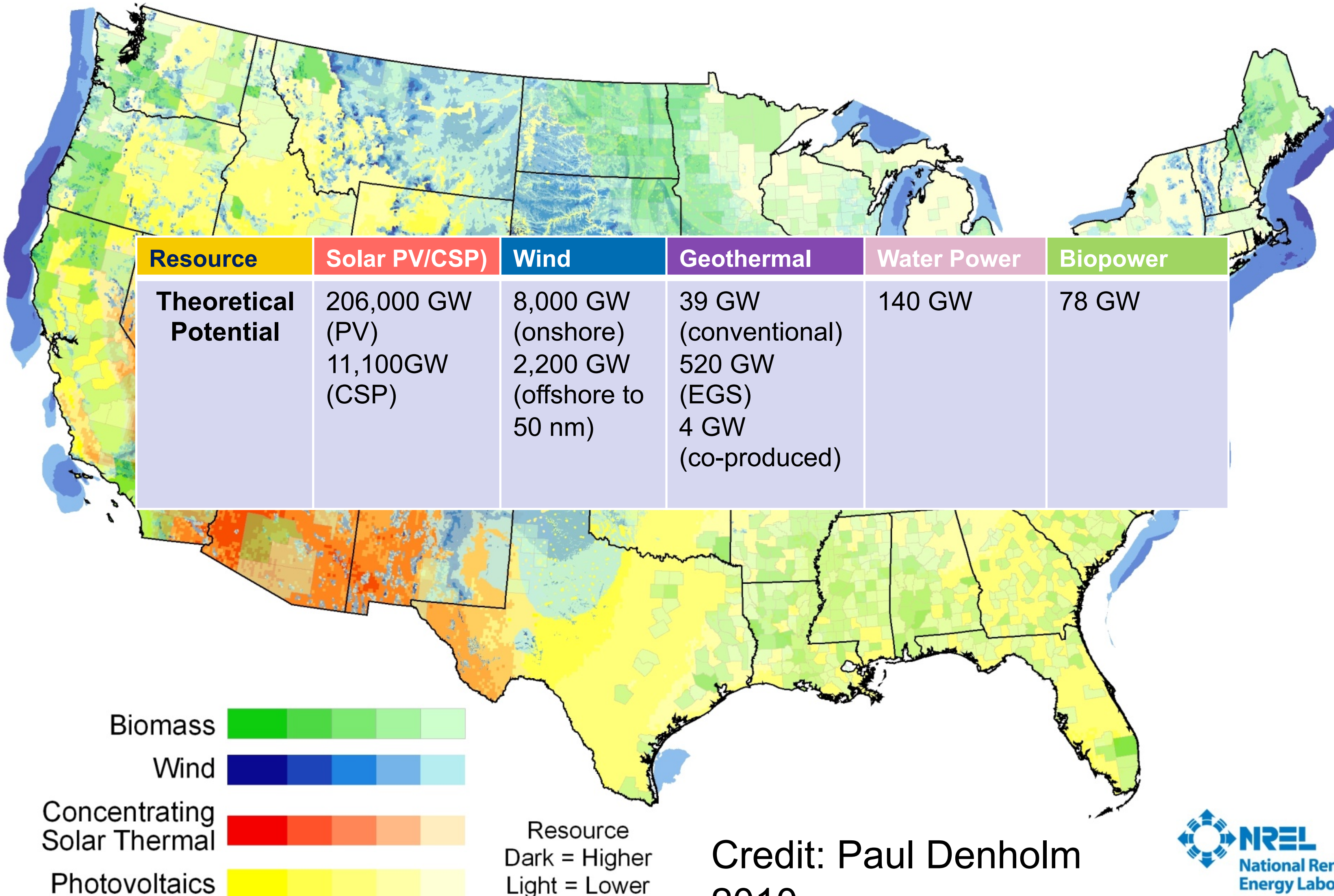
Xu and Zhang, 2007

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

U.S. Renewable Resources



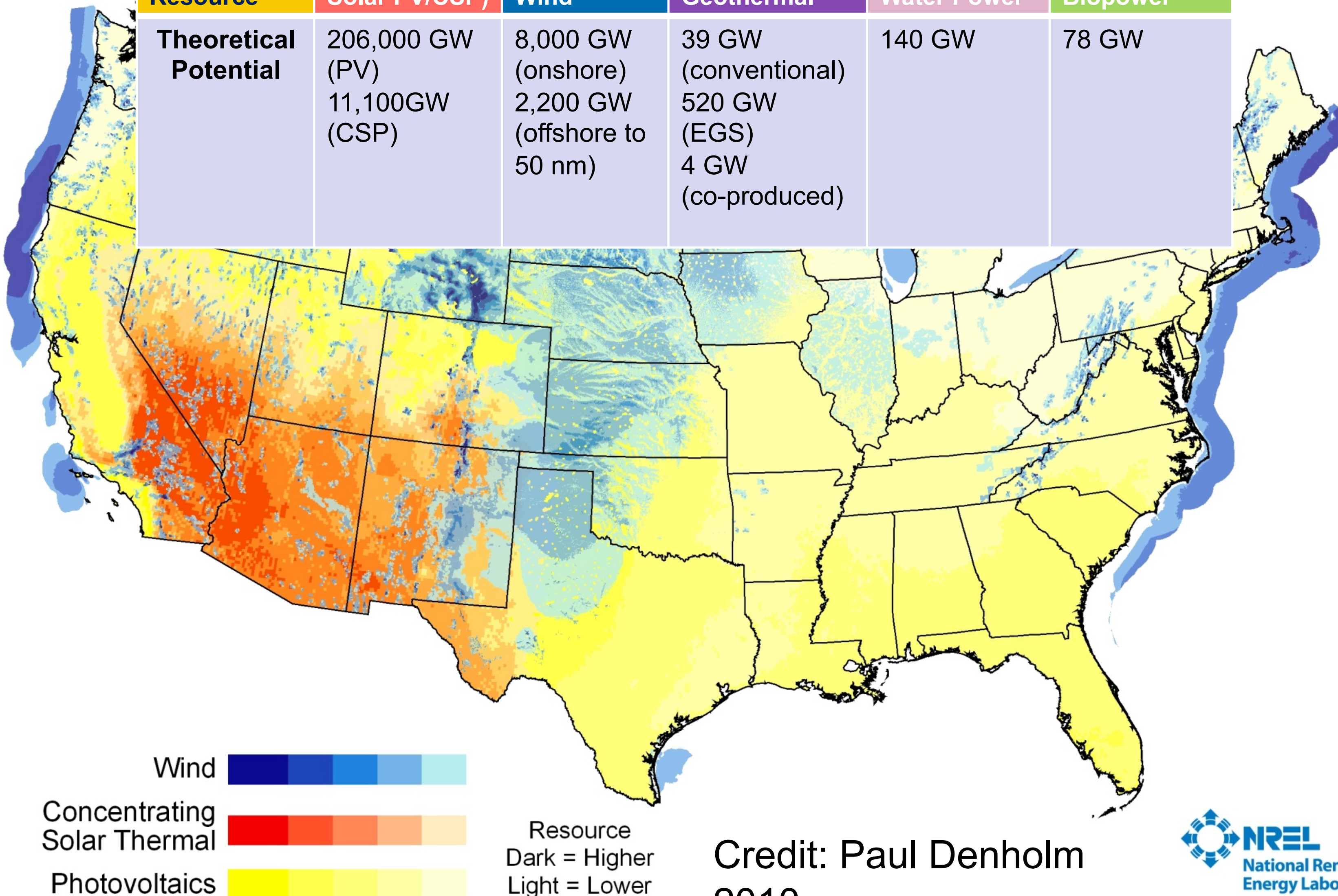
Resource	Solar PV/CSP)	Wind	Geothermal	Water Power	Biopower
Theoretical Potential	206,000 GW (PV) 11,100GW (CSP)	8,000 GW (onshore) 2,200 GW (offshore to 50 nm)	39 GW (conventional) 520 GW (EGS) 4 GW (co-produced)	140 GW	78 GW

Credit: Paul Denholm 2010

NREL National Renewable Energy Laboratory
Innovation for Our Energy Future

Variable Renewable Resources

Resource	Solar PV/CSP)	Wind	Geothermal	Water Power	Biopower
Theoretical Potential	206,000 GW (PV) 11,100GW (CSP)	8,000 GW (onshore) 2,200 GW (offshore to 50 nm)	39 GW (conventional) 520 GW (EGS) 4 GW (co-produced)	140 GW	78 GW



Credit: Paul Denholm 2010

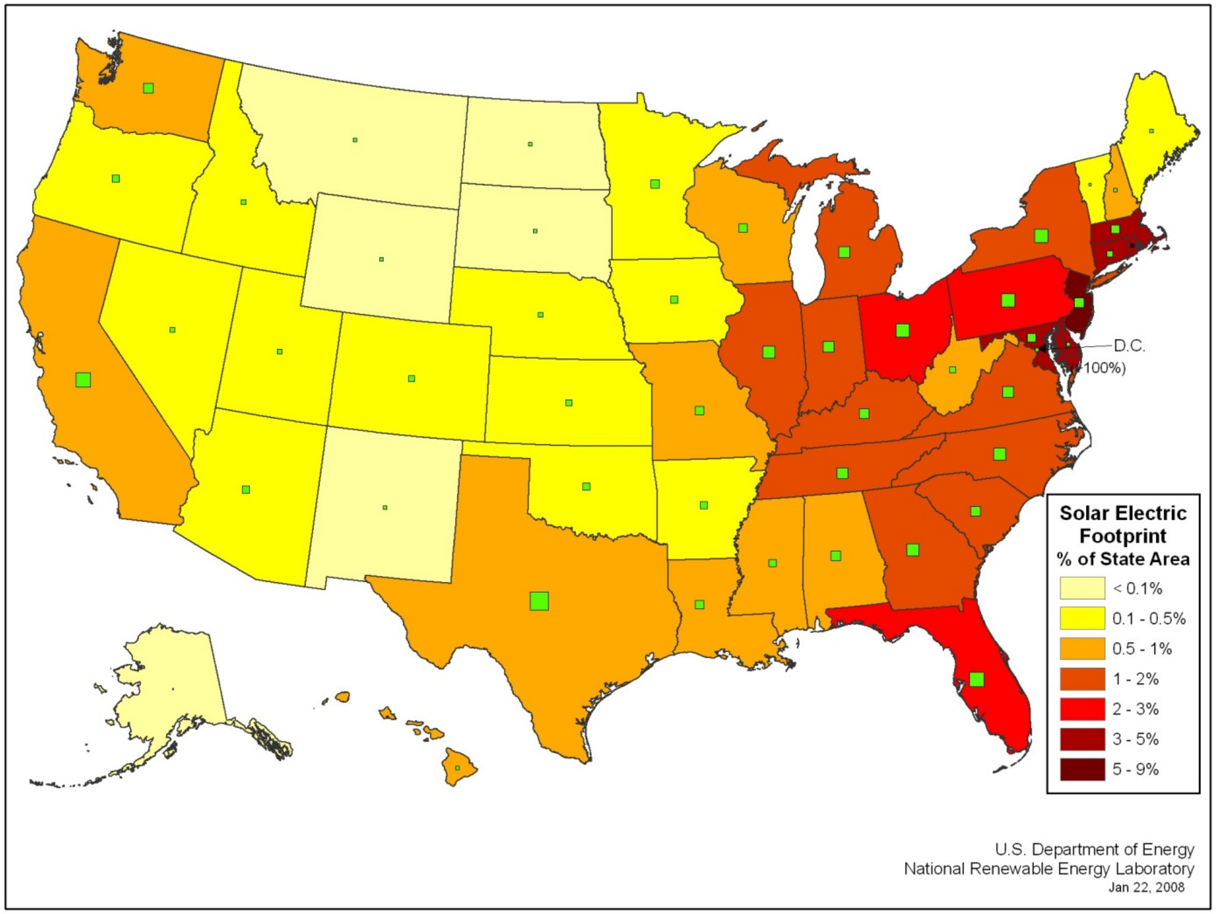
NREL National Renewable Energy Laboratory
Innovation for Our Energy Future

Solar Resource

Credit: Paul Denholm 2010

Meeting all of Georgia's demand with current PV technologies would require about 110-240 m2 per person.

Current area per capita (m2):
Total: 16,422
Roofs: 65
Golf Courses: 29
Urban 1133

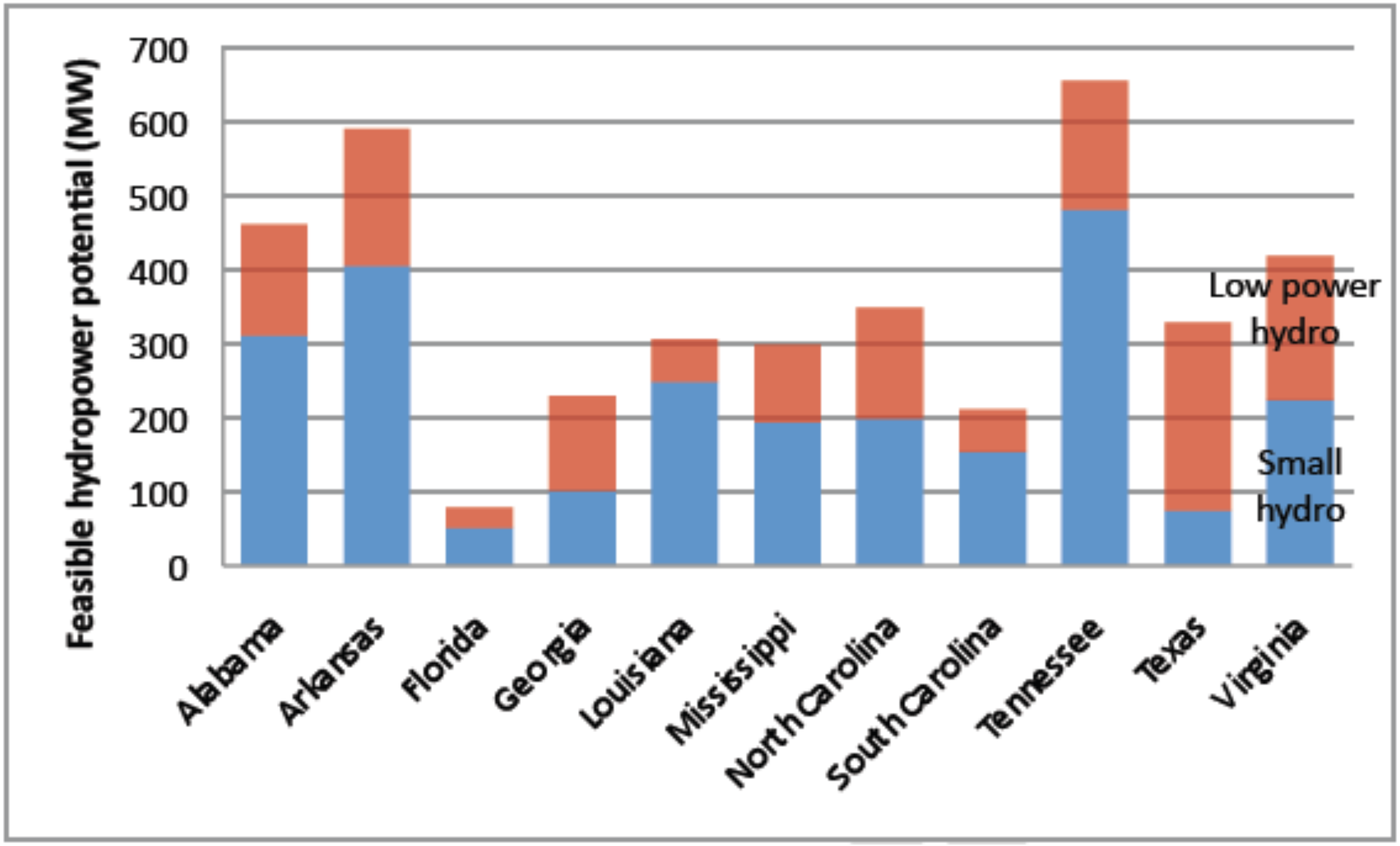


(With biomass, it requires 7000-9000 m2/person, or about 50% of the state area)

Hydropower Potential in the South:

- In 2009, over 15 TWh of hydropower was generated in the South, comprising
  - 38% of the total renewable energy generation,
  - 2.2% of the total electric power generation.
- There is the potential to move from hydropower providing ~2% of electric power to ~ 3-4%.
- With a generating capacity of over 4 GW, conventional hydropower is the largest renewable energy resource in the South (EIA, 2010; Hall, 2006).
- Alabama with a capacity of 1,036 MW leads the South in conventional hydropower generation.
- Tennessee is close behind with a hydro capacity of 848 MW.
- U.S. has 82,000 dams and only 3% of them are generating electricity. Small scale hydropower systems can be easily added to the non-powered dams (Smith, 2010).
- There is potential to cut U.S. fossil fuel consumption and GHG emission in half by applying already demonstrated technology to double the efficiency of U.S. energy use up from 13% (this is based on exergy analysis) (Ayers and Ayers, 2010).

Feasible Hydropower Potential by State:



- The potential capacity of feasible low power and small hydro projects totals more than 3.9 GW
- 62% of these are opportunities for small conventional hydroelectric plants with capacities of less than 30 MW and the remainder could be developed as low-power hydro projects

Distribution of Feasible Projects:

- The feasible projects include about 600 small hydro sites, and 21,700 low-power hydro project sites.
- These are comprised of:
  - • 1,750 feasible projects for conventional turbines
  - • 1,560 feasible projects for unconventional systems
  - • 18,400 feasible projects for microhydro
- A levelized cost of 10¢/kWh was assigned to all feasible projects.

Infrastructure Sustainability

Sustainability Ideas

Environmental Sustainability

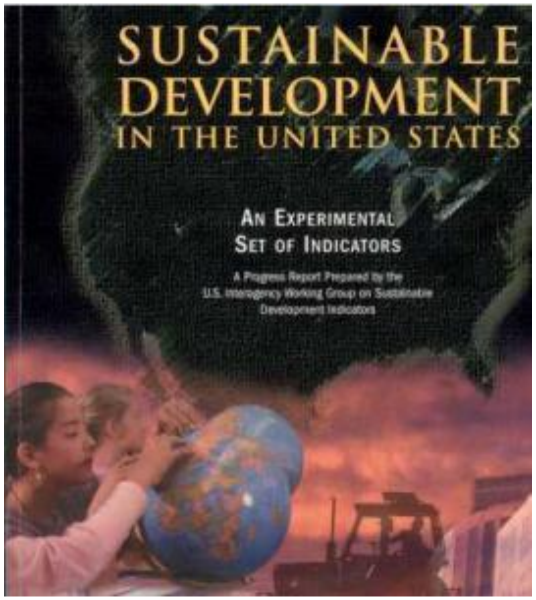
- Human Health,
- Ecosystem Health,
- Biodiversity,
- Natural Resources:
  Protection and Restoration

Economic Sustainability

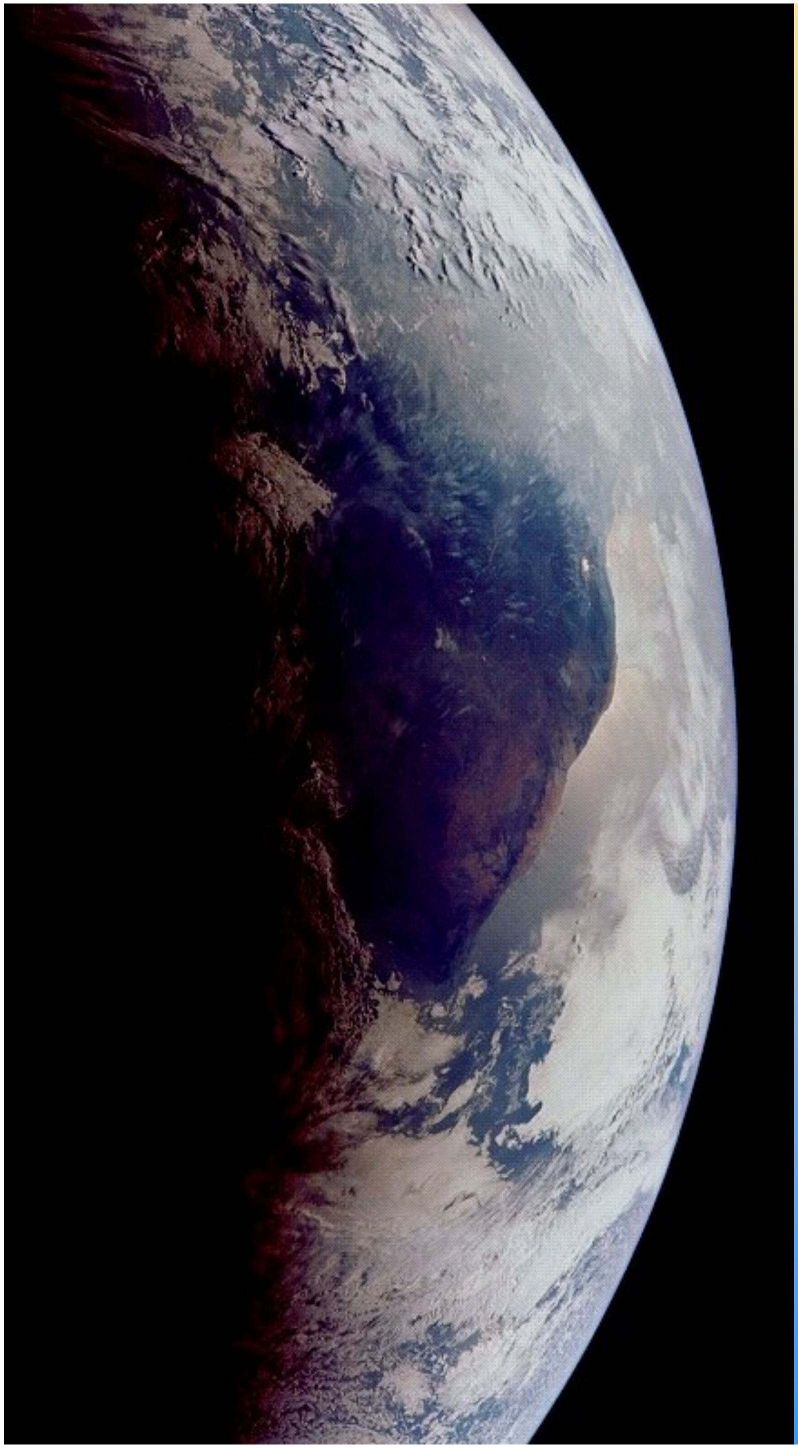
- Productivity,
- Technological Growth,
- Profit and Employment

Societal Sustainability

- Citizens Capacity Building,
- Stakeholder Participation,
- Social Justice and Equity,
- Consumer Choices,
- Provide Opportunity for Useful and Productive Lives



Vibrant, Economically Sound and Livable Communities have realized the benefit of promoting all three attributes.



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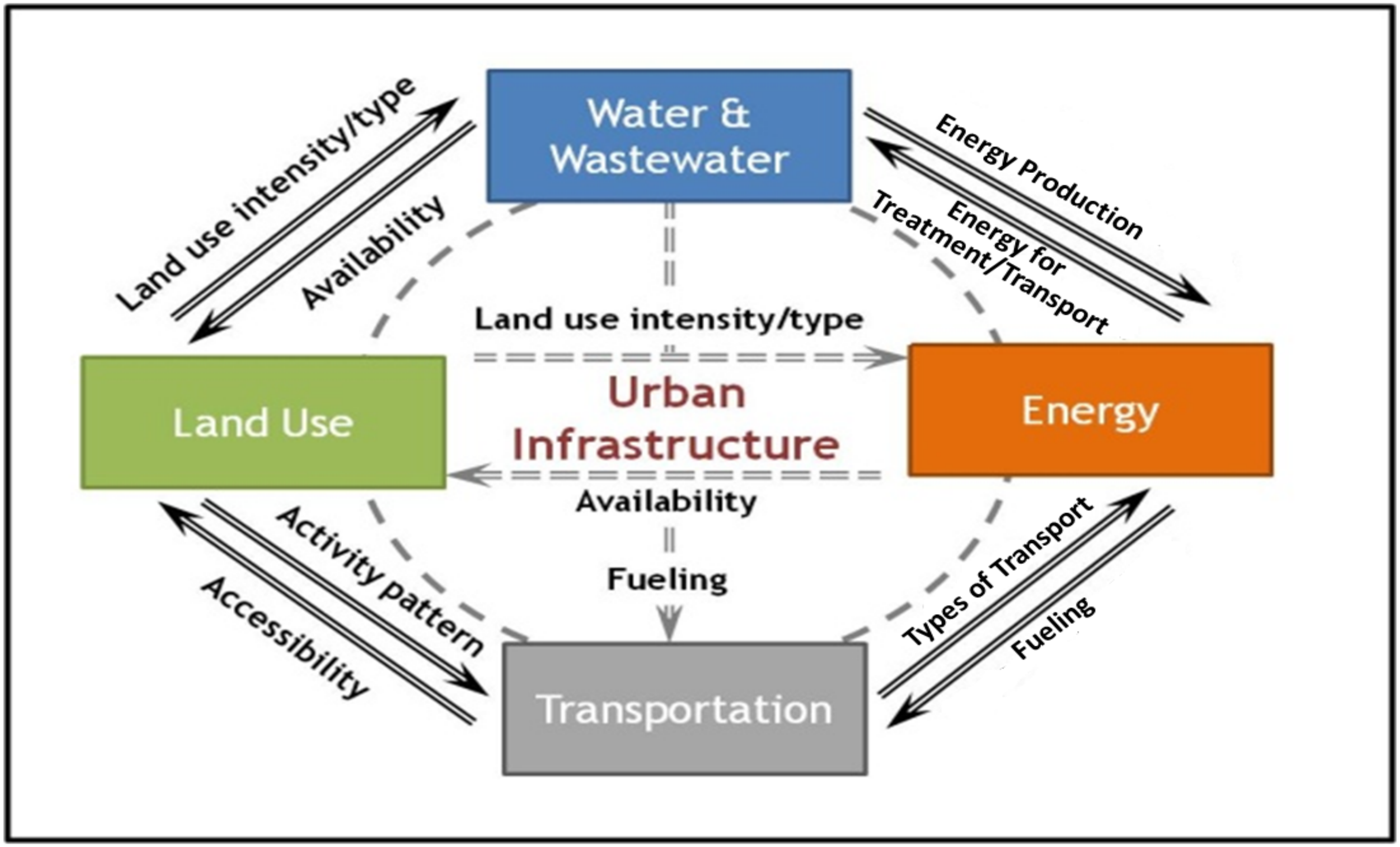
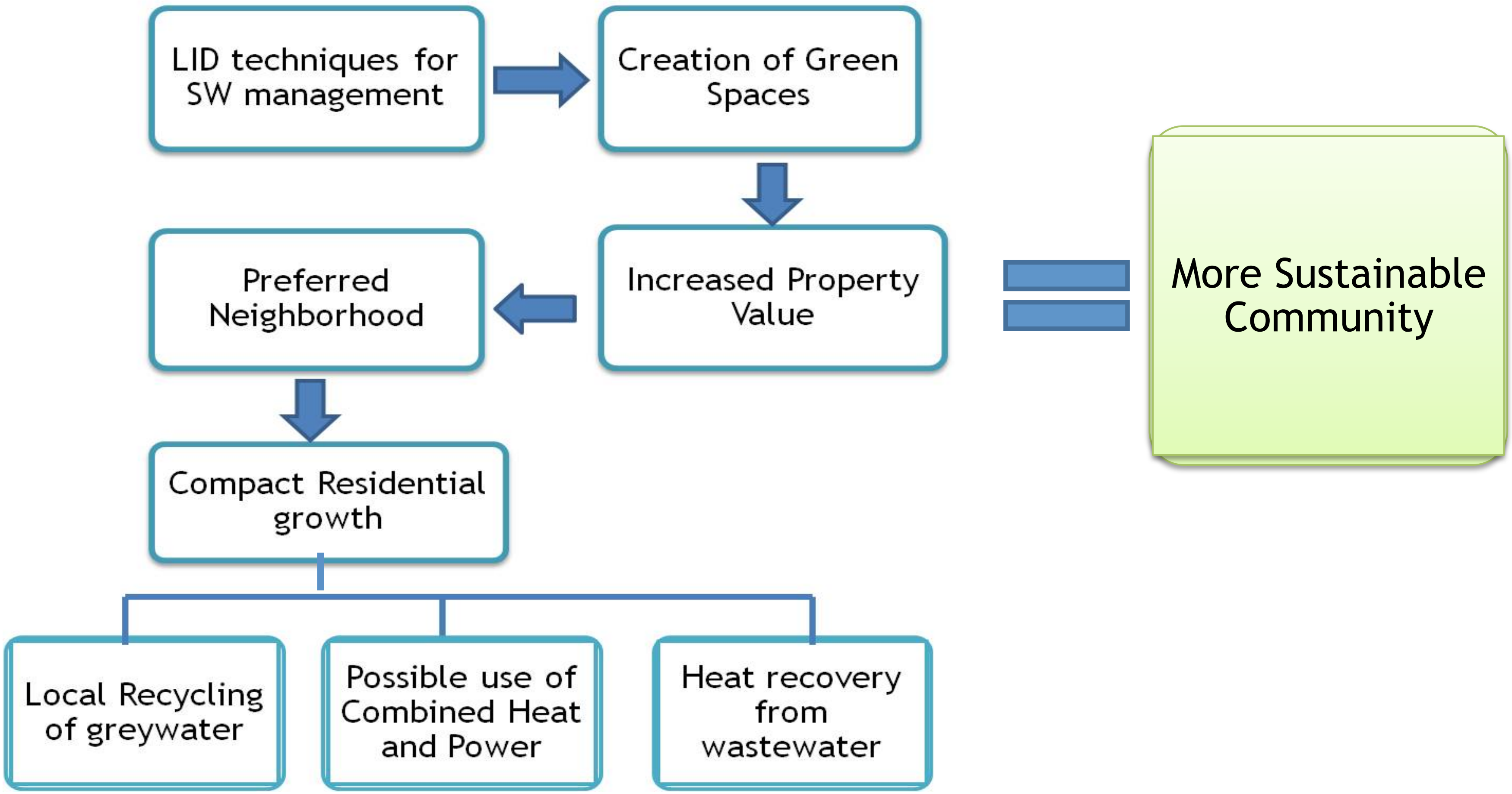
Interdependence of Different Infrastructure Components



Arka Pandit, Hyunju Jeong, John C. Crittenden, Steven P. French, Ming Xu, Ke Li, "Sustainable Infrastructure and Alternatives for Urban Growth", Book Chapter(in review), 2010

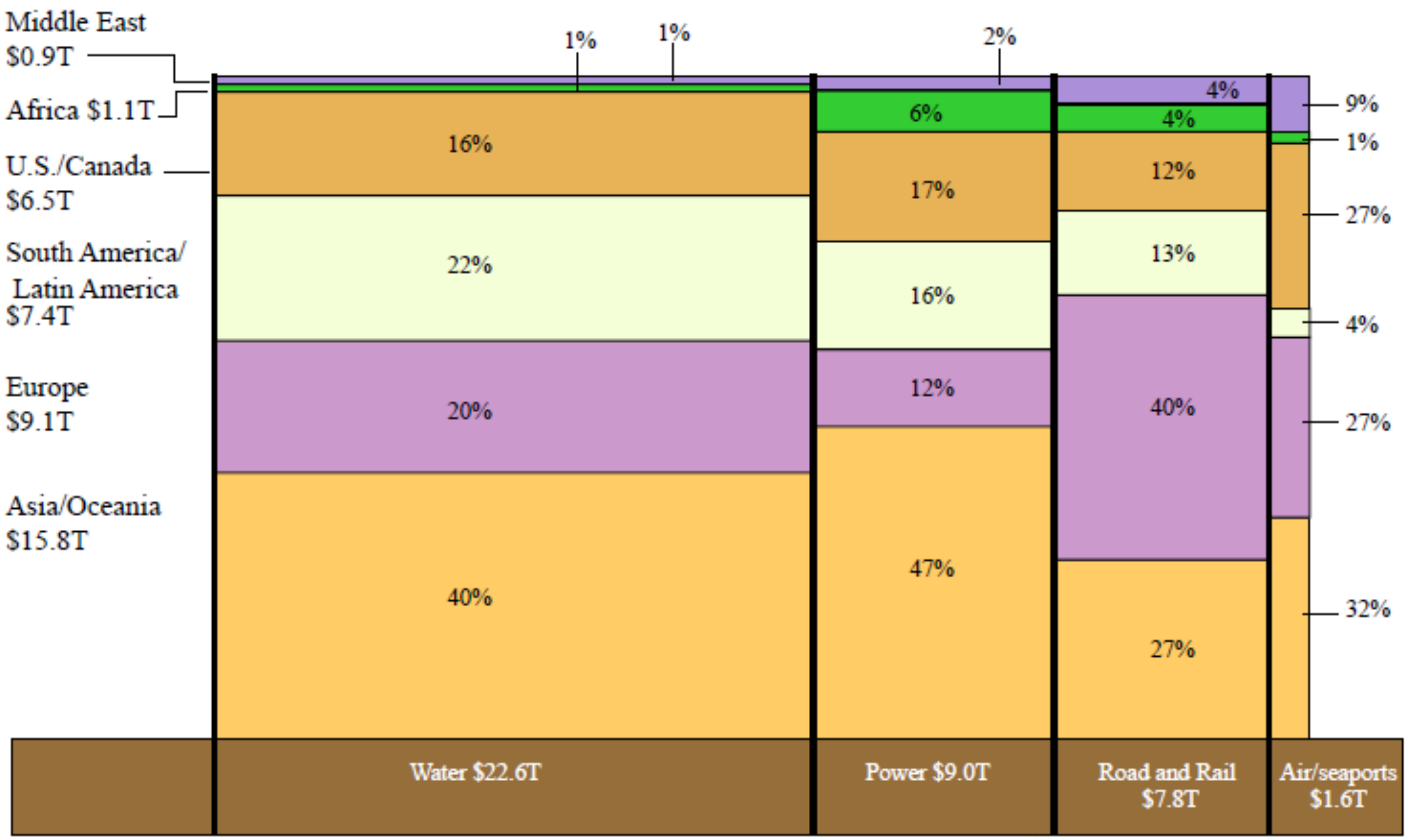
Interconnection between Infrastructure and Socio-economic Environment



Example Flow Schematic for Stormwater (SW) management using LID techniques

Global Infrastructure Demand:

Percentages of total projected cumulative infrastructure investment needed during the next 25 years to modernize obsolescent systems and meet expanding demand broken down by region (rows) and sector (columns).



Total projected cumulative infrastructure spending 2005-2030: **$41 trillion**

Source: Moavenzadeh, F; Frazier, K. The Impact of Globalization on the Built Environment , Lecture Notes, MIT OCW

Infrastructure Ecology:

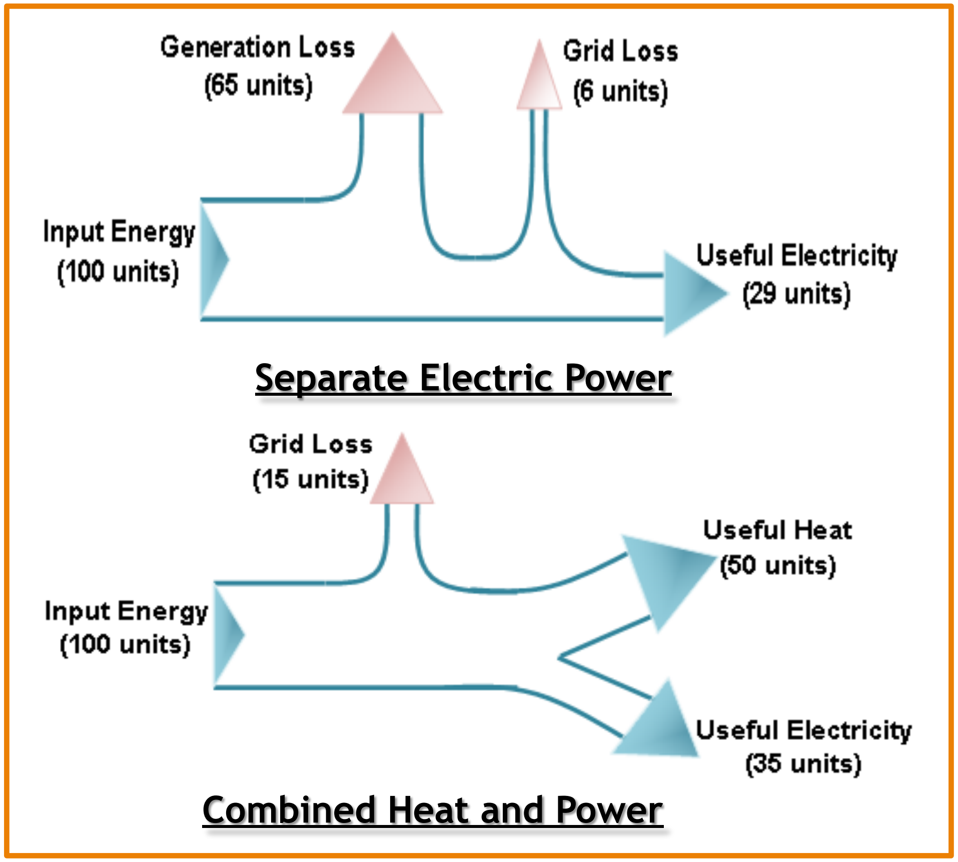
- Reorganizing the linkage among individual infrastructure systems is like changing food chains in ecology. The analogy is infrastructures are species and the urban system is an ecosystem.
- This ***infrastructure ecology*** has a high potential to significantly contribute to solving the gigaton problems.

Combined Heat & Power Generation

In the U.S., combined heat and power

- Accounted for ***7%*** of U.S. electricity ***generation capacity*** as in 1999.
- Had a typical ***system efficiency*** of ***68%***, with some new systems exceeding 90%.
- Emitted on average $^{1}/_{10}$ of the nitrogen oxides (NO_X) per kWh of average utility grid electricity.
- Could potentially provide ***20%*** of U.S. ***electricity by 2030***, ***reducing CO_2*** emissions by ***0.8 gigatons*** annually

Source: http://www.aceee.org/energy/chp.htm

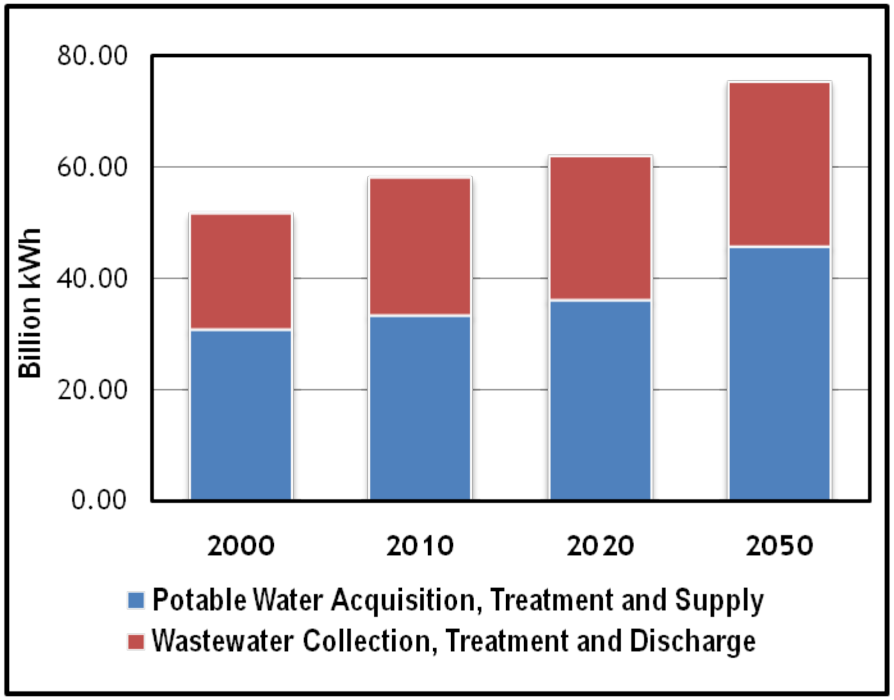


Transportation Alternatives:

Plug-In Hybrid Electric vehicles (PHEVs) (Source: PNNL, 2007)

- ❑ 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 usage (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%

Energy for Water in US:



Energy consumption by Public Water and Wastewater Utilities (in Billion kWh)[1]

- About **4%** of the total electricity consumption in US is for water and wastewater sector.
- About **19%** of the total electricity consumption in California is for water and wastewater sector (average).

Average Energy requirement for different water and wastewater treatment technologies[2]

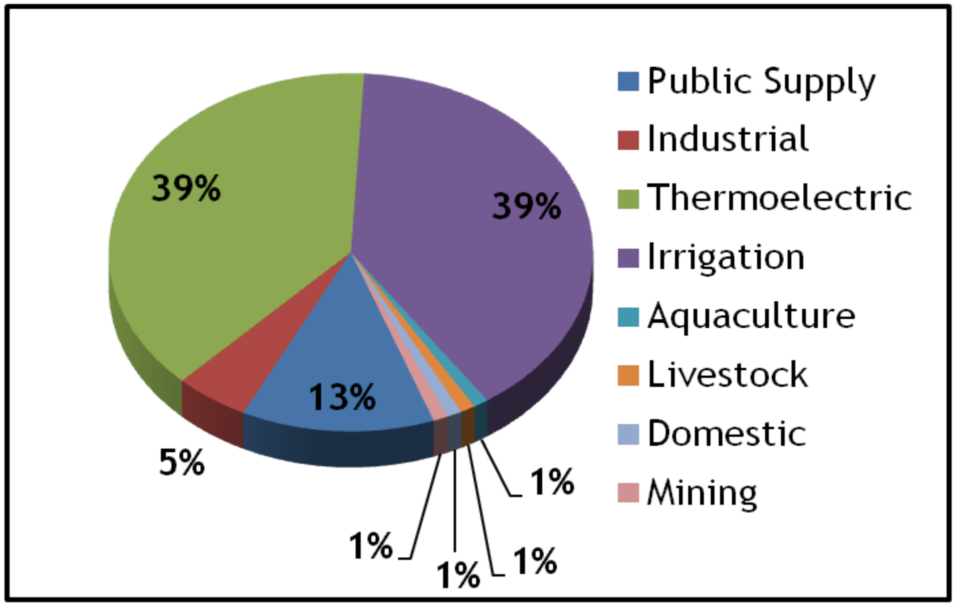
Water Treatment*	kWh/MGal
Surface Water Treatment	220
Groundwater Treatment	620
Brackish Groundwater Treatment	3,900-9,700
Seawater Desalination	9,700-16,500
Wastewater Treatment**	**kWh/MGal**
Trickling Filter	950
Activated Sludge	1,300
Advanced Treatment without Nitrification	1,500
Advanced Treatment without Nitrification	1,900

*Includes collection but does not include distribution
**More advanced treatment require more energy

[1] EPRI, Water & Sustainability, Volume 4, 2002
[2] Stillwell, A S, et al. Energy-Water Nexus in Texas, 2009

Water for Energy in US:

- Thermoelectric power generation accounts for approximately **39%** of total freshwater and **52%** of fresh surface water withdrawals.
- The evaporative loss from thermoelectric power generation sector is about **3.3 billion Gal/day**.
- The average (weighted) evaporative consumption of water for power generation over all sectors is around **2.0 Gal/kWh**.

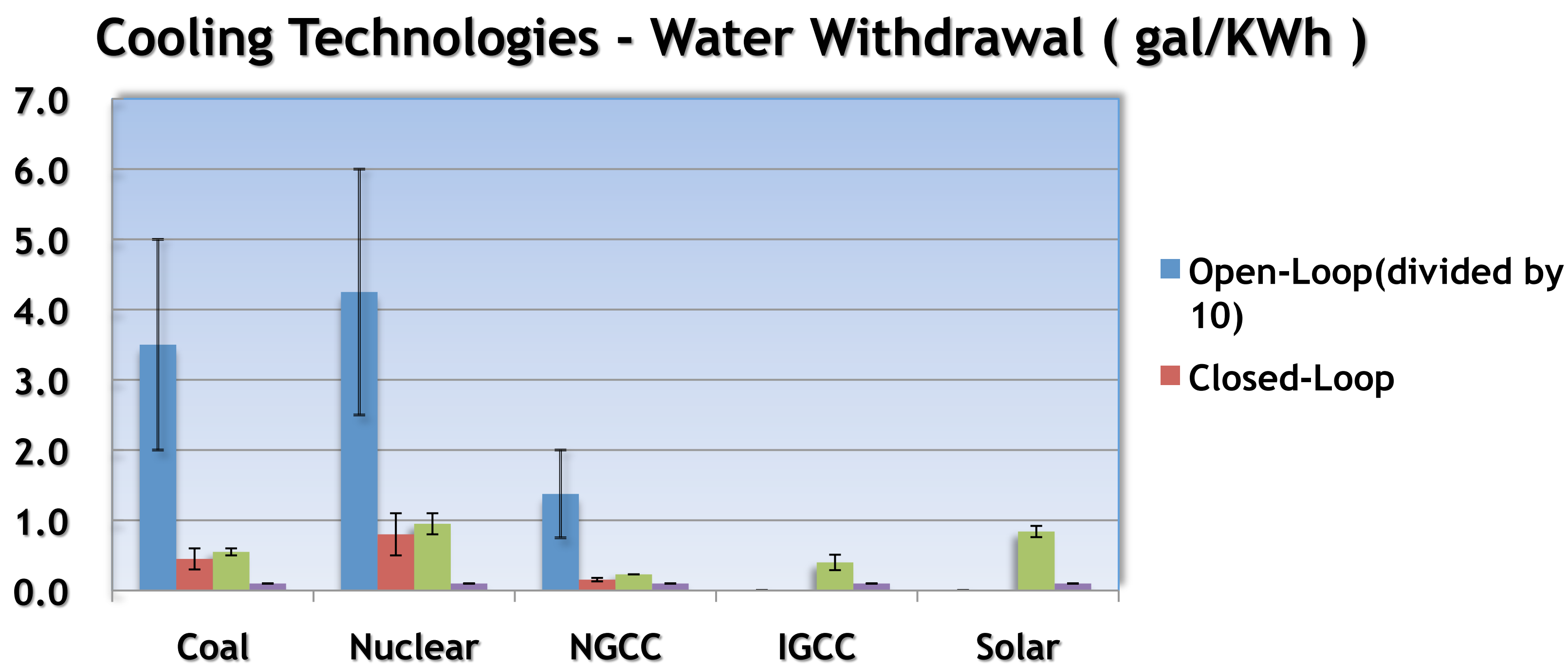


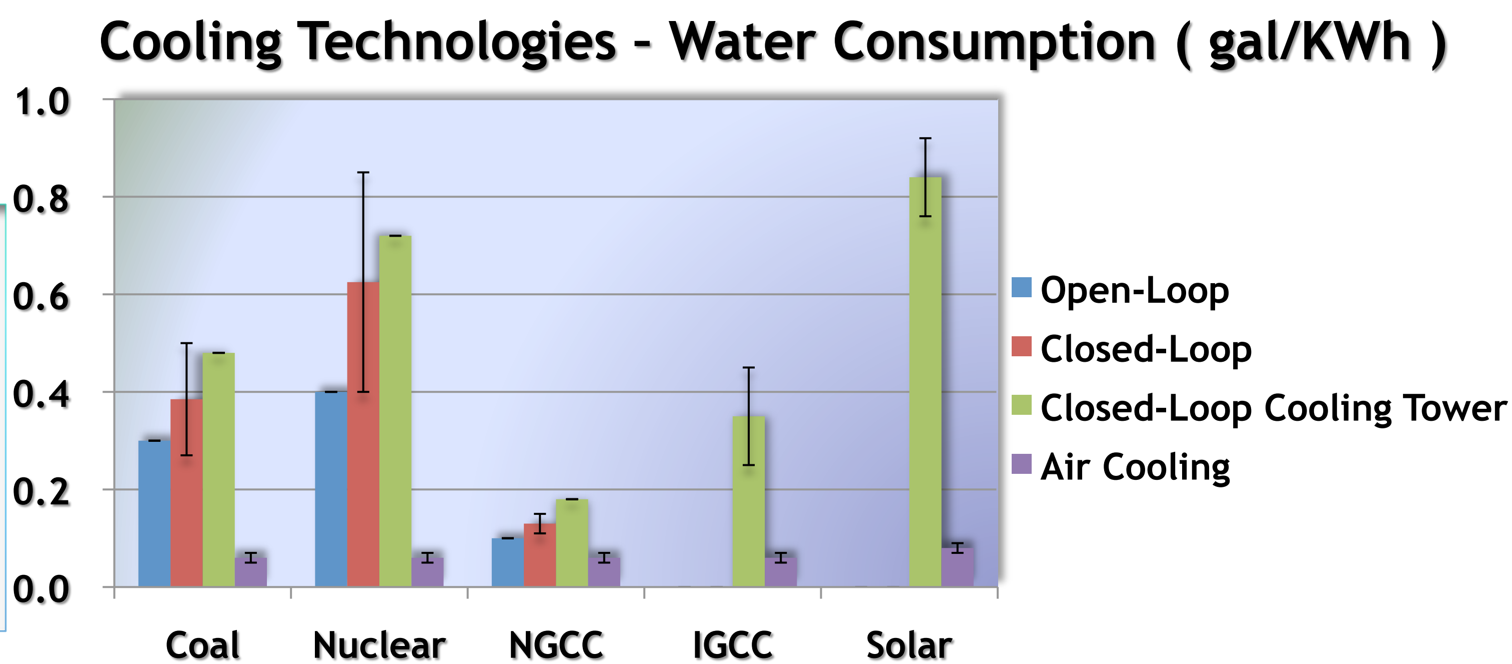
US Freshwater withdrawals by sector
(Total withdrawal: 345 Billion Gal/d)

Source: US DOE, Energy Demand on Water Resources, 2006

Consumptive Water Use by different Energy Sources

Energy Source	Gal/kWh (Evaporative loss)
Hydro	18.27
Nuclear	0.62
Coal	0.49
Oil	0.43
PV Solar	0.030
Wind	0.001





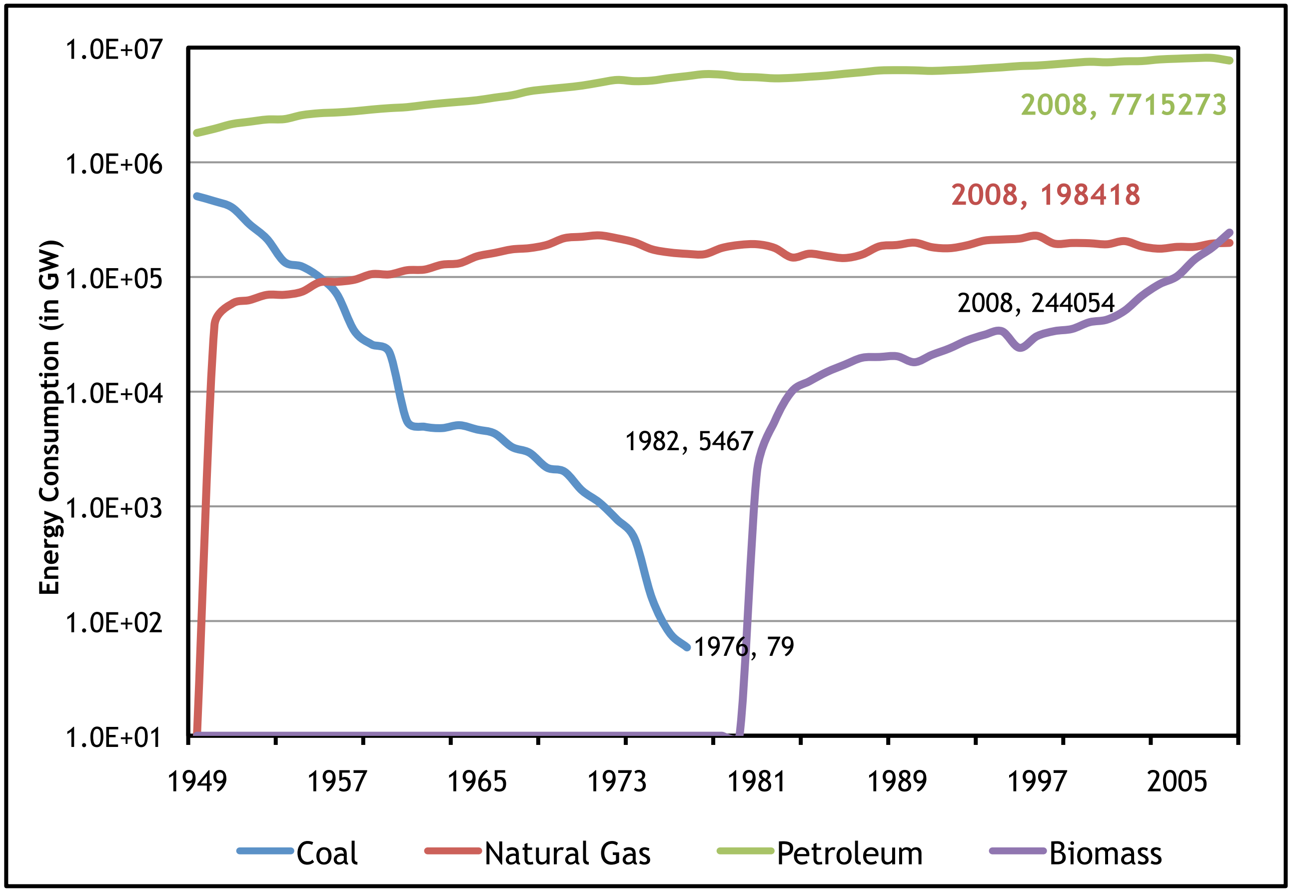
Note:

*NGCC: Natural Gas Combined-Cycle
*IGCC: Integrated Gasification Combined-Cycle
*Wind, Photovoltaic Solar and Natural Gas Combustion Turbine excluded

Source: Stillwell, A S, et al. Energy-Water Nexus in Texas, 2009

Energy for Transportation in US:

- The primary energy consumption of the transportation sector was ***931.3 GW*** in 2008.
- The transportation sector accounts for ***28%*** of the total energy consumption.



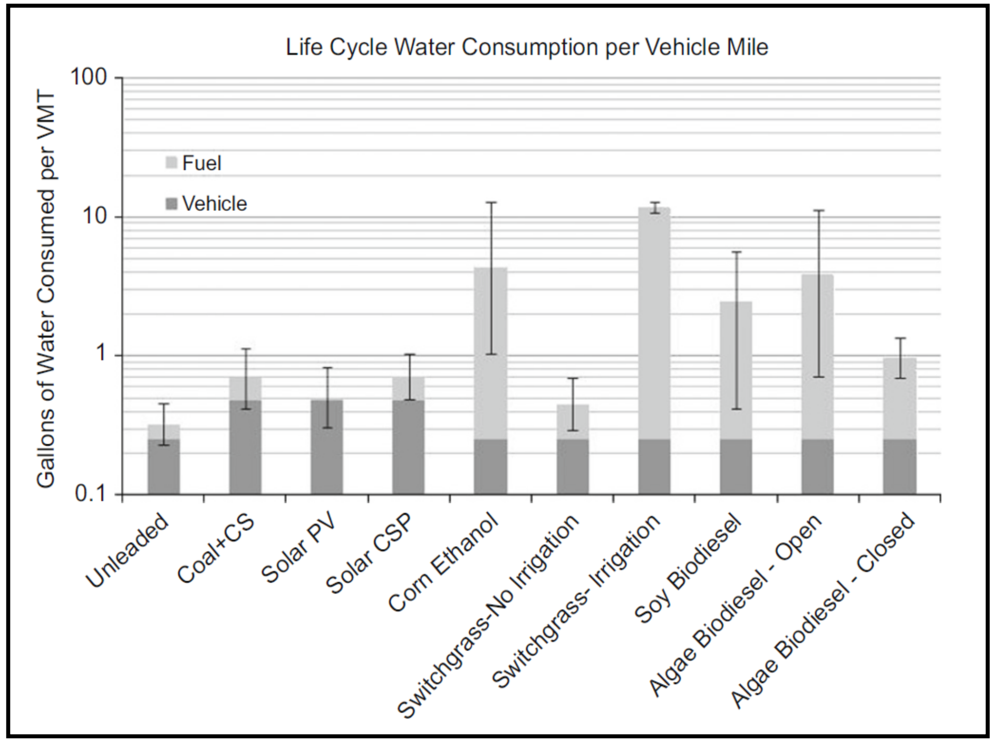
Energy consumption of the transportation sector by source

- In the US transportation sector accounted for (as in 2007):
  - ***71%*** of the total petroleum consumption
  - ***3%*** of the total Natural Gas consumption
  - ***3%*** of the total renewable energy consumption (due to the use of fuel ethanol).

Source: US EIA Database

Water for Transportation in US:

Unit : Gal/ kWh	Low	High	
Coal*	0.007	0.027	Mining + washing
Petroleum/ Oil*	0.03	0.076	Extraction + refining
Natural gas*	0.01	0.01	Extraction + processing
Corn-ethanol**	1.26	19	Assuming,15 % irrigation for U.S.
Cellulosic ethanol**	0.13	0.431	No irrigation
Cellulosic ethanol**	16	19	Irrigation
Soy-biodiesel**	0.392	8.98	Assuming, 4% irrigation for U.S.
Algae biodiesel**	0.839	1.762	Enclosed
Algae biodiesel**	0.895	18.351	Open



Life Cycle consumptive water use by different transportation fuel alternatives

(Source: Harto, C; et al., Life cycle water use of low-carbon transport fuels, Energy Policy, 2010)

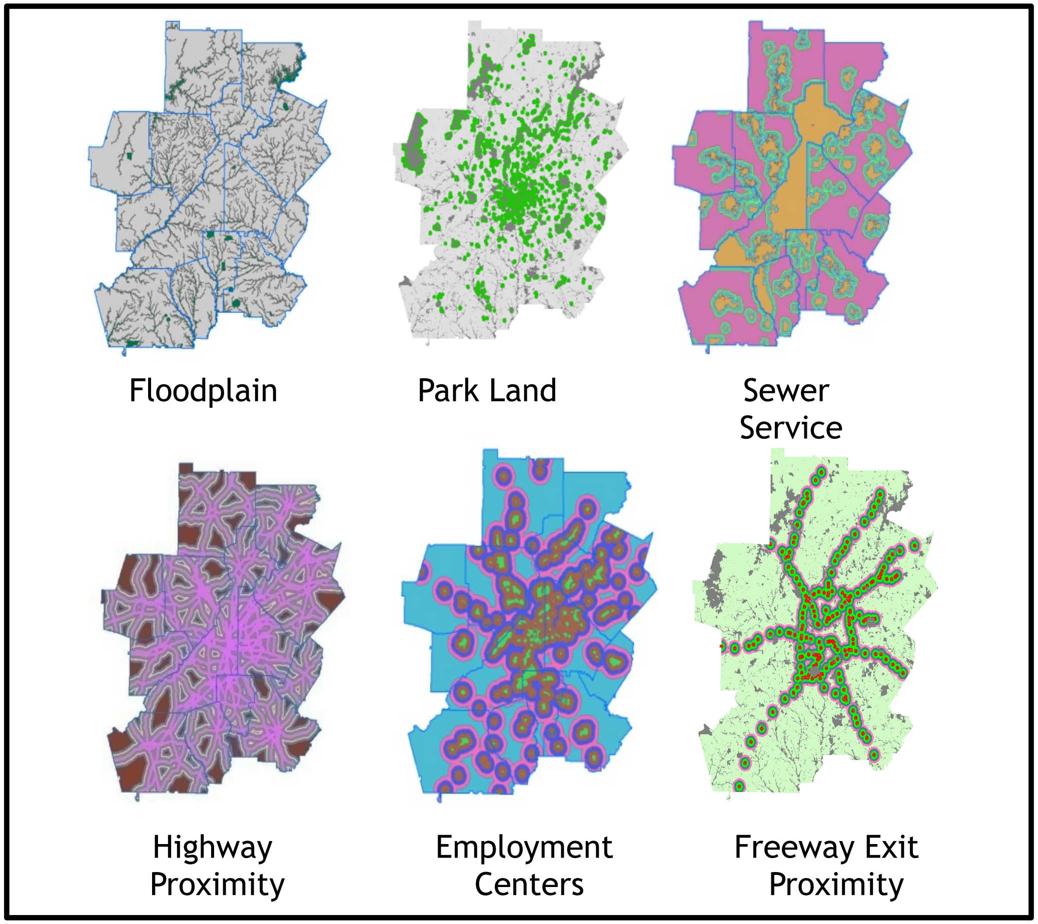
*DOE, 2006
** Harto, C; et al., Life cycle water use of low-carbon transport fuels, Energy Policy, 2010

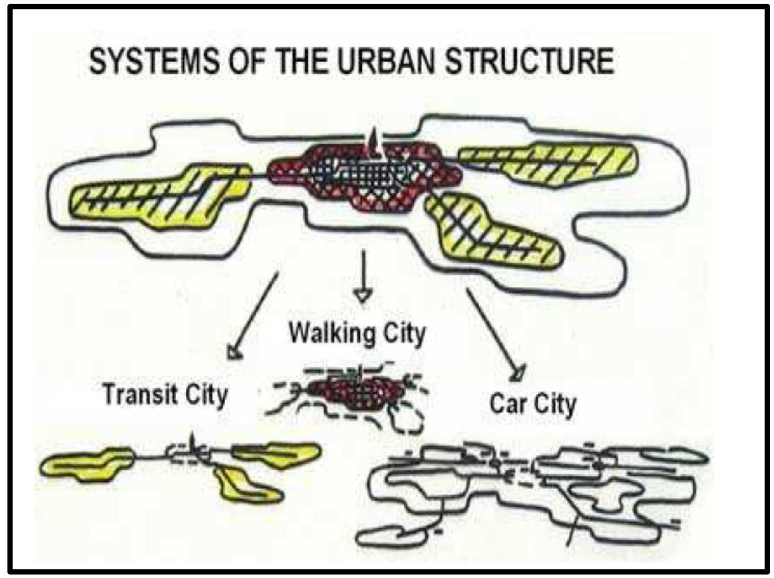
Energy Water Nexus – Phoenix Vs. Atlanta

		The City of Phoenix		The City of Atlanta	
Residential Water Demand	Indoor (gpcd)	48[a]	1999 data in Chapter 4 of The Water Environment of Cities (Crittenden et al., 2009)	71	2001 data in The World's Water 2008 ~ 2009: The Biennial Report on Freshwater Resources
	Outdoor (gpcd)	110[a]		20	
Power Use	Residential Electricity , kWh/person-day	36	2005 data Brown, Southworth, and Sarzynski (2008)	41	2005 data Brown, Southworth, and Sarzynski (2008)
	Fuel, kWh/person-day	5.5		12.3	
Water Consumption for Electricity Production	gal/kWh	7.85 (Arizona)	National Renewable Energy Laboratory (2003)	1.65 (Georgia)	National Renewable Energy Laboratory (2003)
Electricity Consumption for Water Supply and Treatment	Water kWh/MG	8,600	Scott et al. (2009) Conveyance, 4600 Pumping, 2600 Water Treatment, 100 Water Distribution, 1300	1,700[b]	City of Atlanta Watershed Management, Thomas (2007), DOE (2006)
	Wastewater kWh/MG	10,700	Scott et al. (2009) Wastewater Collection and Treatment, 1500 Reclaimed Water, 9200	1,830[b]	

a. The numbers are modified assuming 4 people for one household
b. The numbers are estimated based the water and wastewater production of City of Atlanta, the electricity use of Atlanta Watershed Management Department(Thomas, 2007), and the Electricity demand for waster supply and wastewater treatment of South Atlantic Region(DOE, 2006)

Land Use and Infrastructure:





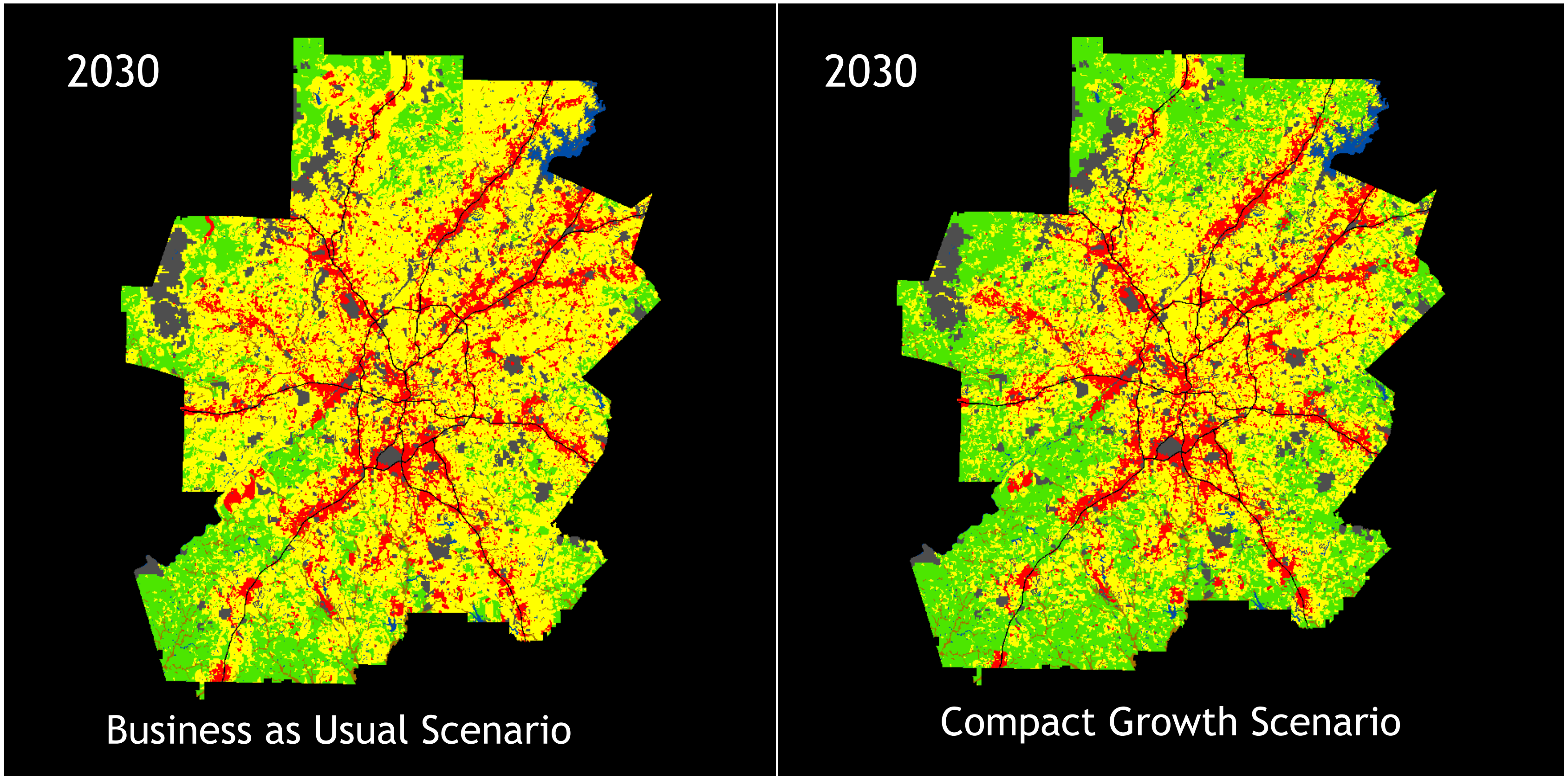
Interaction between Land Use and Transportation infrastructure
(Source: http://www.ymparisto.fi)

Selected Development Suitability Factors (shown for Metro Atlanta region) Courtesy: French, S; GT

- The model allocates exogenously-determined housing and employment totals based on land suitability

- Though the interconnection between land use and transportation is more obvious, adequate energy and water infrastructure are required to sustain the desired land use pattern.

Growth Scenarios in Atlanta:

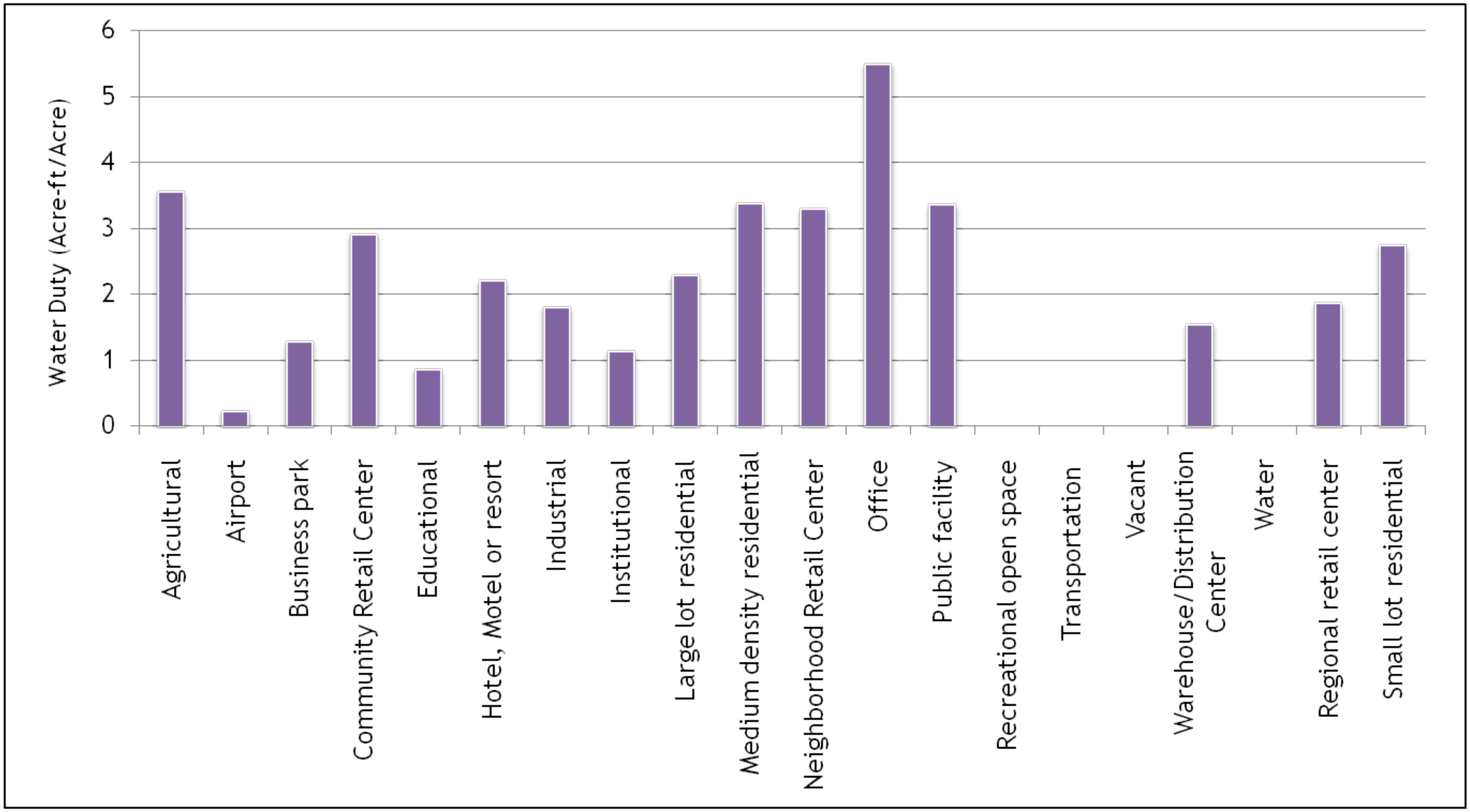


<u>Comparison of two different growth scenarios for Atlanta in 2030 using *What-If* urban modeling tool</u>
Courtesy: French, S; GT

Land Use and Water Demand:

Water demand = Water duty * Area of the land-use type

Land-use types and their corresponding water duty factors (Maricopa County, AZ)



Source: 2005 MAG's Land-use data

Courtesy: Li, K; UGA

LID Techniques for SW Management:

Passive Treatment of Stormwater:

- Allows natural systems to treat the stormwater runoff, thus improving the water quality and reducing the burden on centralized treatment system.

Potential effects of LID technique implementation in urbanized areas of Southern California and San Francisco Bay region: Source: NRDC, A Clear Blue Future, 2009

	Water Savings (acre-ft/yr)	Energy Savings (MWh/yr)	CO_2 Savings (Mt CO_2-equiv.)
Low	229,000	573,000	250,500
Medium	314,500	867,000	379,000
High	405,000	1,225,500	535,500

Bioretention Basins

Pervious Pavement

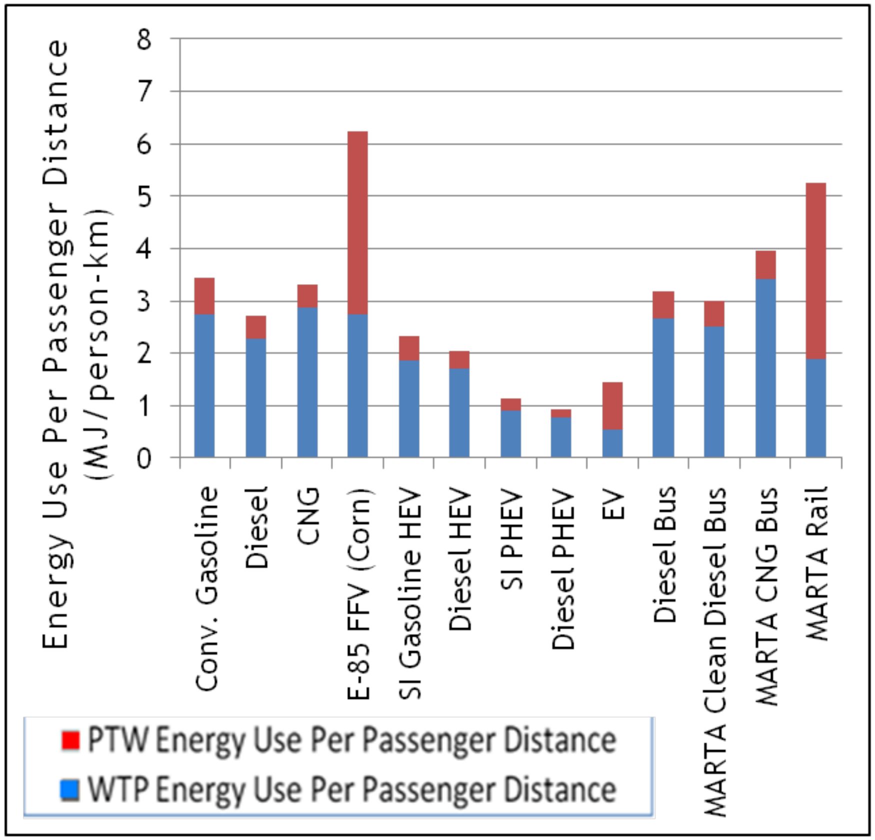
Green Roofs

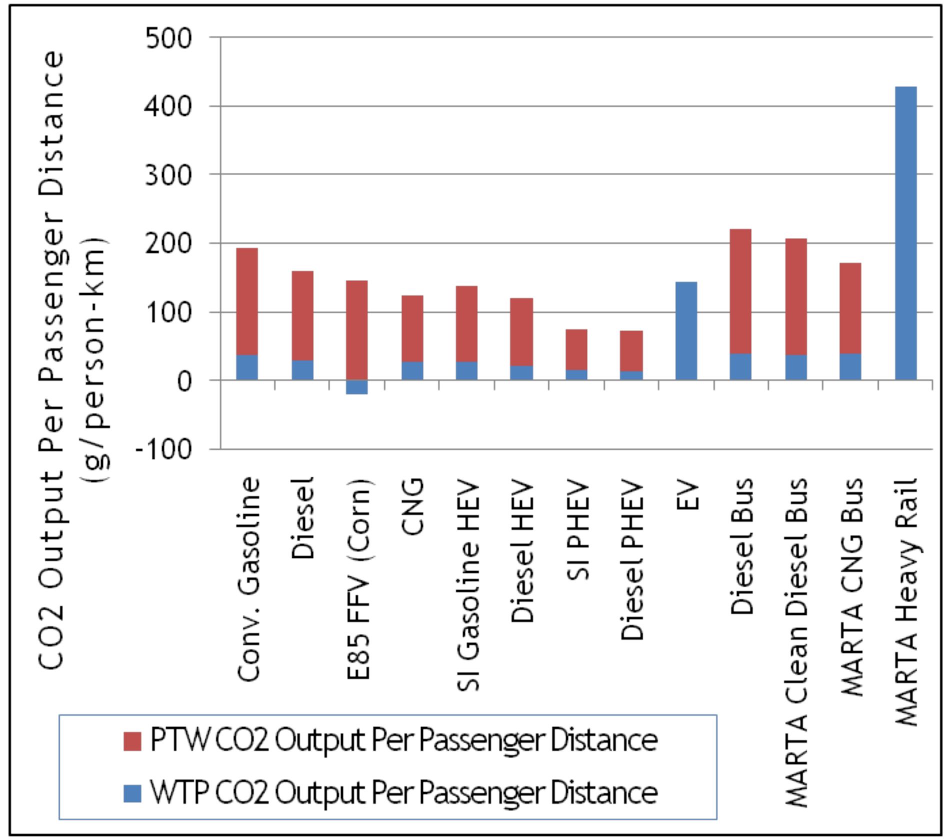
Water/Wastewater/Stormwater Alternatives

Concept	Alternatives	Effects
LIDs	✓*Green Landscaping*	For metro Atlanta area of 775,000 acre, tree cover increase of 29 %(in 1996) to 40%(Scenario) ➔ Stormwater runoff decrease of 20%[1]
	✓*Rainwater Harvesting*	Possible to supply water for outdoor watering, toilet flushing, etc. occupying around 50 %(for the Metropolitan North Georgia) [2] of water demand
Wastewater Reclamation	✓*Onsite Wastewater Reclamation*	200 kWh/MG for MBR treatment , UV-ozone disinfection, pumping[3] (Much less than conventional energy consumption for wastewater treatment and water supply)
	✓*Centralized Wastewater Reclamation*	In 2009, use of reclaimed water for non-potable use saved the City of Tucson, AZ 5.5 billion gallons of potable water.
Energy and Nutrient Recovery	✓*Anaerobic sludge digestion gas*	CHP fueled by the biogas[4] from RM Clayton WRC (City of Atlanta) ➔ Possible to provide 25 % of electricity use of the facility
	✓*Urine Separation*	Possible to remove nitrogen up to 50 ~ 60 %[5] of wastewater 55 MJ per 1 kg ammonia fixation[6]
Efficient Water Use	✓*Small flow fixture*	The City of Calgary: Water saving percentages Dual flush toilet (75%), Clothes washer (50%), low-flow showerhead (35%), faucet aerator (25%), and dishwasher (45%)[7]
	✓*Xeriscaping*	Not need outdoor watering
	✓*WaterSense® labeled products in 2009*	Saving more than 36 billion gallons of water ➔ 4.9 billion kilowatt hours of electricity

[1]American Forests(2001) Urban ecosystem analysis - Atlanta Metro Area
[2]The Metropolitan North Georgia Water Management District
[3]Memon et al. (2007) Life cycle impact assessment of greywater recycling technologies for new development
[4]Pullen. *Leading by Example, Energy, Water and Climate Initiatives*. City of Atlanta, 2010.
[5]Larsen et al. Source Separation: Will we see a paradigm shift in wastewater handling? *Environmental Science & Technology. feature*. 2009, Vol. 43.
[6]FAOSTAT, *Consumption in Nutrient in the United States and the World in 2006, Fertilizer.* FAOSTAT, 2008.
[7]The City of Calgary. *Water Efficient Fixtures*. last updated on 2009 May.

Energy for Transportation: Atlanta





Preliminary Energy & CO_2 Results, Atlanta (Base Case) Courtesy: Bras, B; GT

- Poor environmental performance of electric vehicles, all sizes, due to coal fired power plants
  - Georgia Power's Plant Bowen emits about 0.9kg CO_2/kWh
- MARTA rail & bus performance bad due to low ridership

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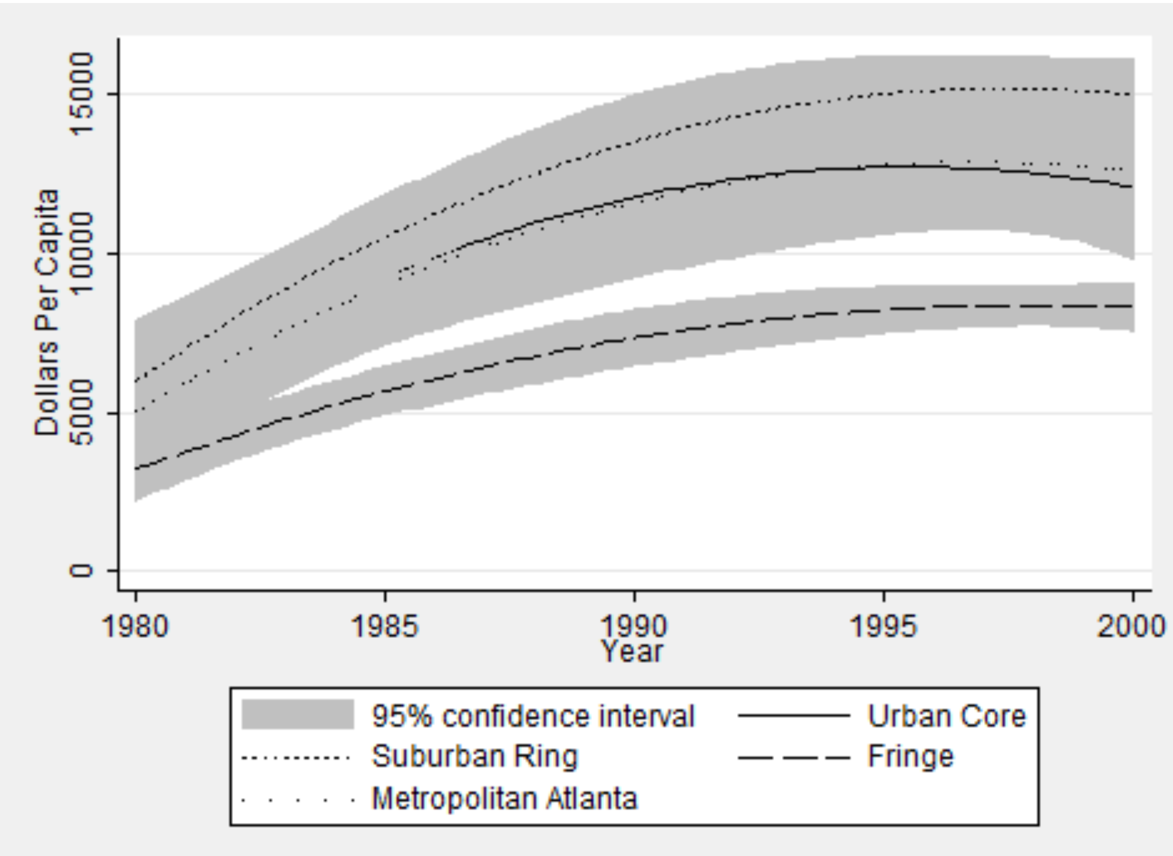
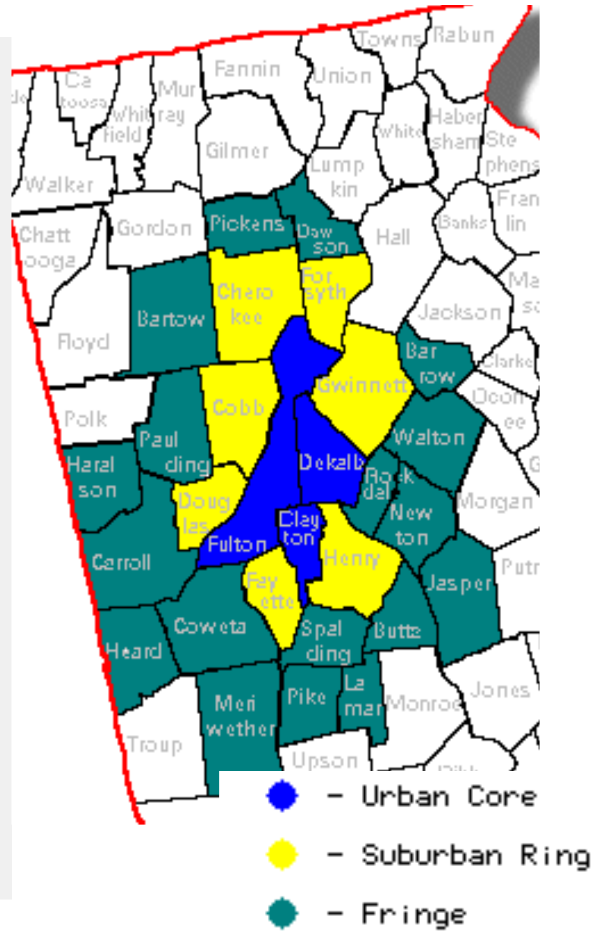
- Concluding Remarks

Development in Atlanta Metro



Genuine Progress Indicator, using Counties



- Suburban ring highest absolute values of GPI with slower growth 1990-2000
- Urban core not sustainable from 1990-2000
- Fringe counties have lower absolute values but steady positive development

Genuine Progress Indicator (GPI)

Sum of 24 measures grouped into 4 dimensions of sustainability

- Economic (5): income – adjusted for equality, underemployment, non-market labor
- Social (5): social cohesion – including family, leisure, and crime
- Environment (5): cost of pollution (air, water, noise, waste)
- Resources (9): natural and man-made capital

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 natural, engineered, social and economic systems.