US Water-Energy Nexus: Data gaps, uncertainties, and future projections

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Roundtable on Science and Technology for Sustainability
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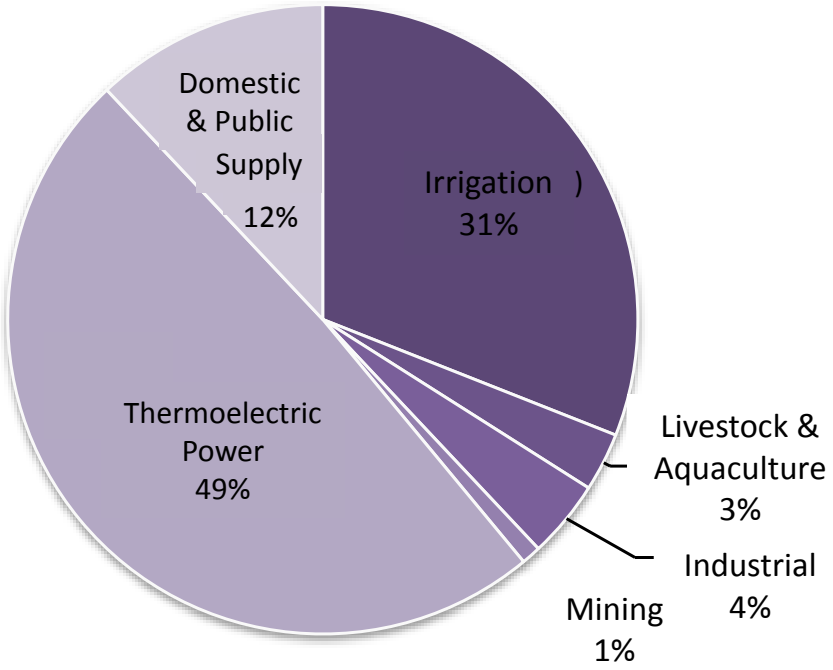
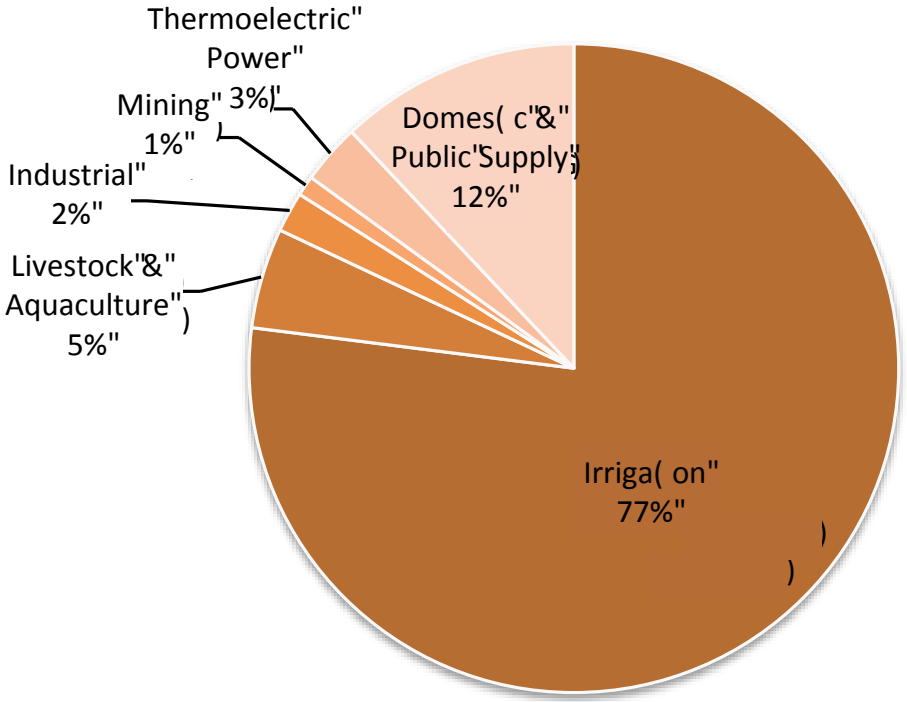
Water withdrawals and consumption

Withdrawals

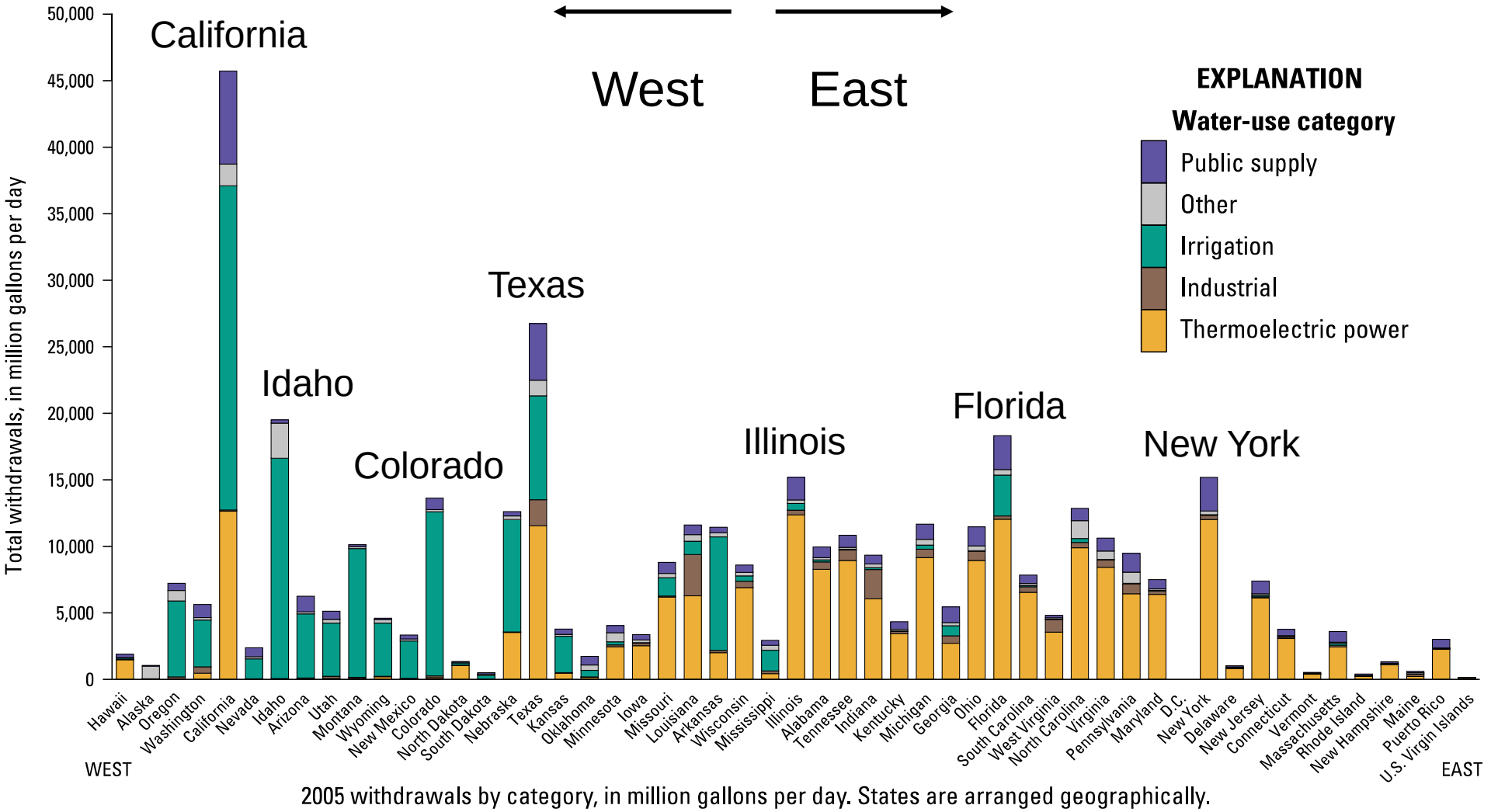


Consumption



Data Source: Kenny, J. F.; Barber, N. L.; Hutson, S. S.; Linsey, K. S.; Lovelace, J. K.; Maupin, M. A. *Estimated Use of Water in the United States in 2005*; U.S. Geological Survey: Washington, D.C., 2009.

Water withdrawals by state



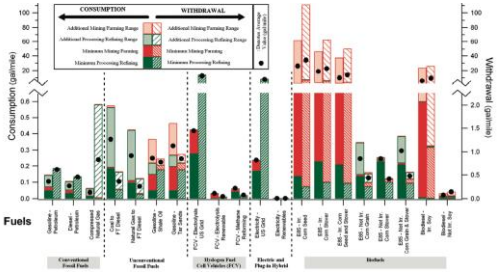
2005 withdrawals by category, in million gallons per day. States are arranged geographically.

Kenny,J.F.,Barber, N.L., Hutson, S.S., Linsey, K.S., Lovelace,J.K., and Maupin, M.A., 2009, Estimated use of water in the United States in 2005: U.S. Geological Survey Circular 1344.

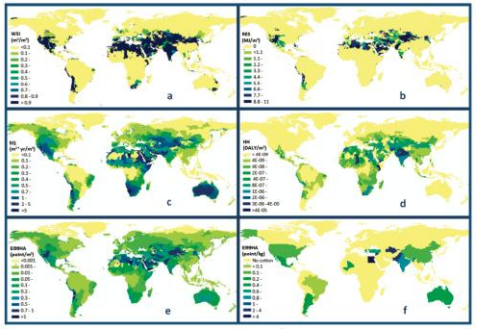
Life-cycle water impacts data needs

- Water use inventory
  - Consumption
  - Withdrawals
- Source/location
  - Watershed
  - Surface/ground
- Water stress index
  - Baseline water use
  - Water availability
- Human/ecological impacts
  - Drinking water infrastructure, baseline ecological diversity, etc.

King & Webber (2008)



Disconnect between detailed life-cycle inventories and robust impact assessment

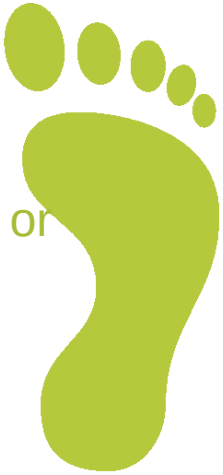


Pfister et al (2009)

Water “footprint” by color

- An attempt to maintain physical units for water use while accounting for both water use & water quality impacts
- Incorporates the concept of “green water”, penalizing rainfed crops

Blue: water withdrawn from ground or surface water for human uses



Green: rainfall consumed by crops or otherwise used for human purposes

Gray: the quantity of water needed to dilute aquatic pollution to reach applicable standards

Concept from Gerbens-Leenes et al (2009)

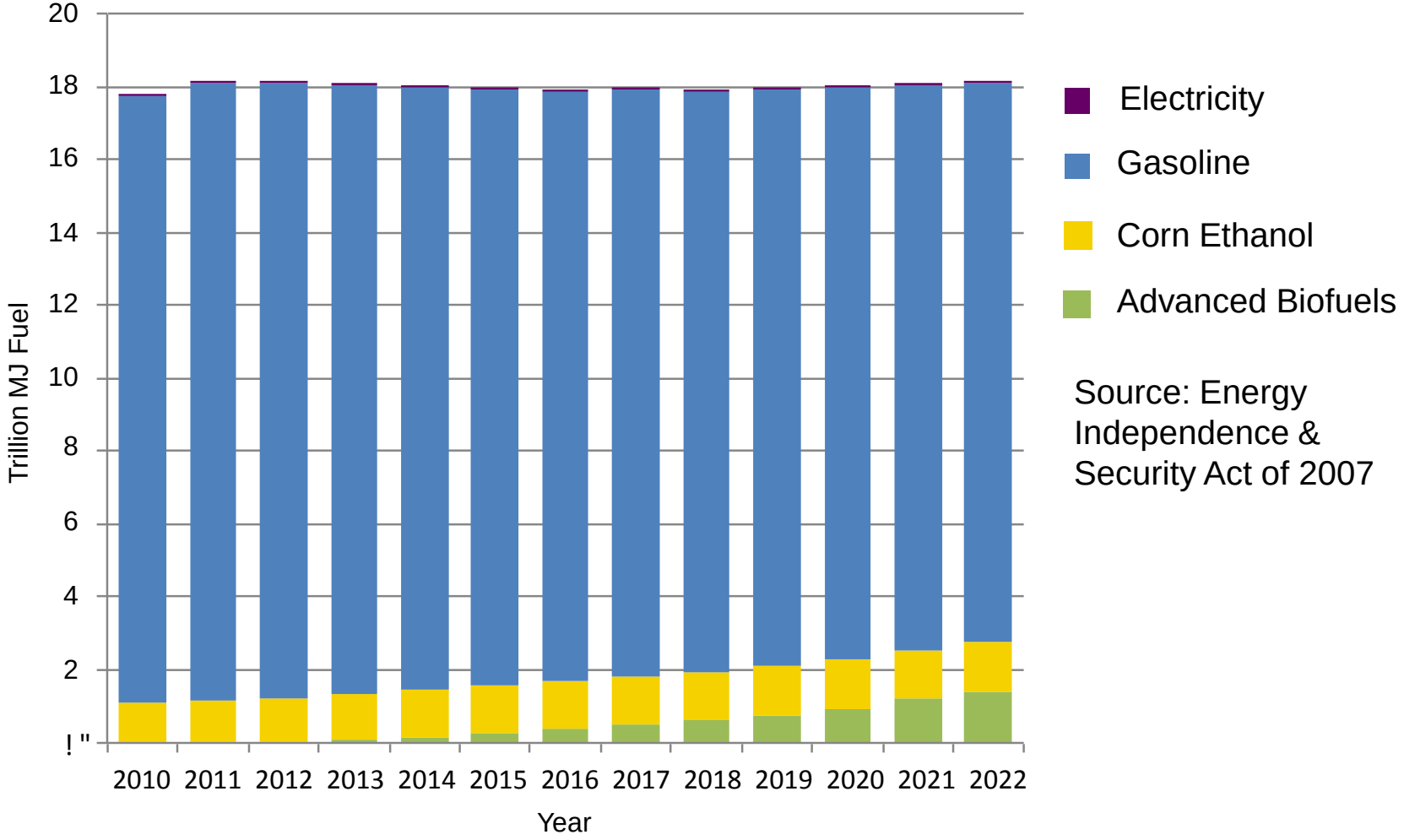
Green water: implications for biofuels

- Rainfed low-input, high-yield grasses often have higher ET rates than row crops they could potentially replace
- These higher ET rates likely closer to that of native vegetation
- Artificially high water table resulting from replacement of native vegetation with row crops can cause salination of soil
- Higher ET of biofuel crops not necessarily detrimental

Sources: wiu.edu; news.illinois.edu

Energy-water nexus: Transportation energy

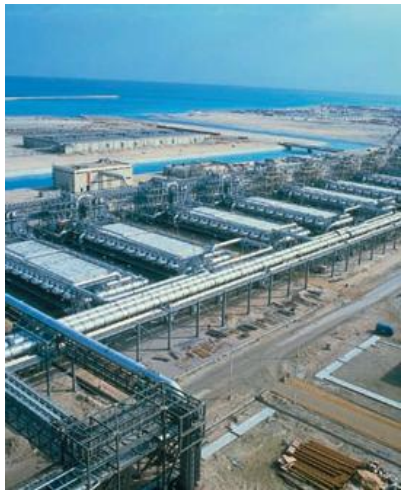
How reliant on fresh water resources will future transportation fuels be, and what are the implications?

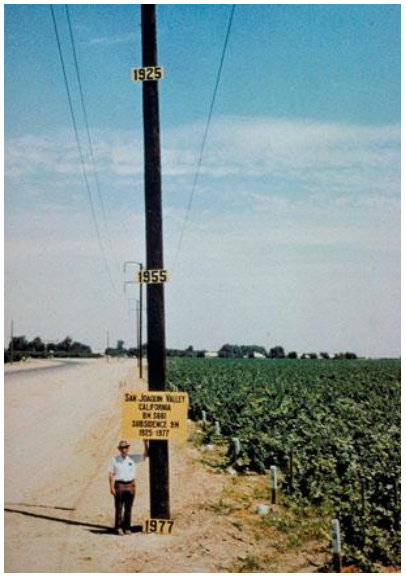


Source: Energy Independence & Security Act of 2007

Motivation

- Depletion of water resources results in:
  - Subsidence
  - Saltwater intrusion
  - Habitat disruption
  - Exacerbation of drought conditions
  - Need for energy-intensive alternative supplies





US water withdrawals

[Biofuels]

Ethanol from corn grain, corn stover, & Miscanthus

[Electricity]

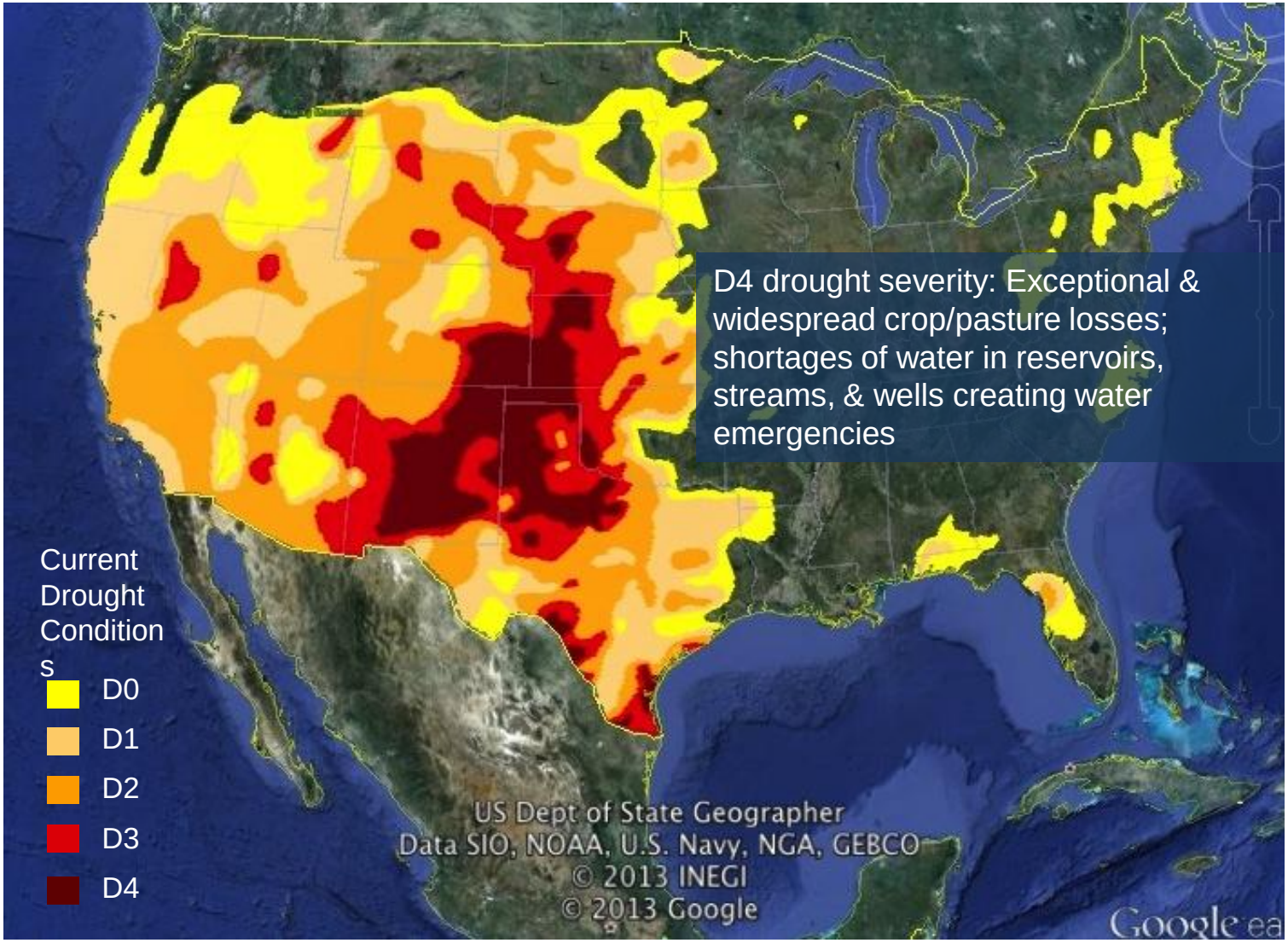
National & regional electricity mixes

[Petroleum]

Gasoline from conventional crude & oil sands

Data Source: Kenny, J. F.; Barber, N. L.; Hutson, S. S.; Linsey, K. S.; Lovelace, J. K.; Maupin, M. A. *Estimated Use of Water in the United States in 2005*; U.S. Geological Survey: Washington, D.C., 2009.

Current drought conditions

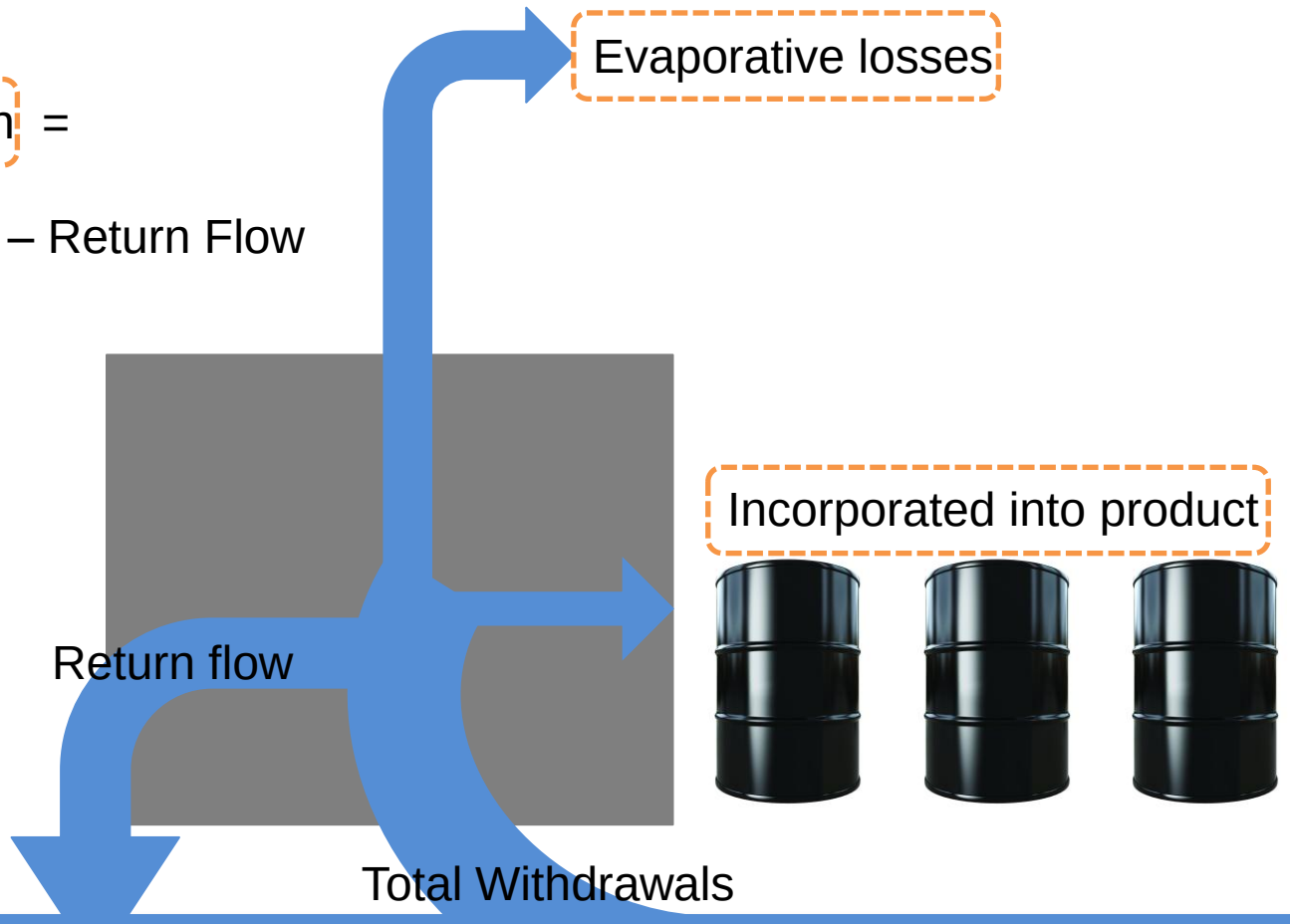


Drought Data: U.S. Drought Monitor May 28th, 2013

Water use metrics

Total Consumption =

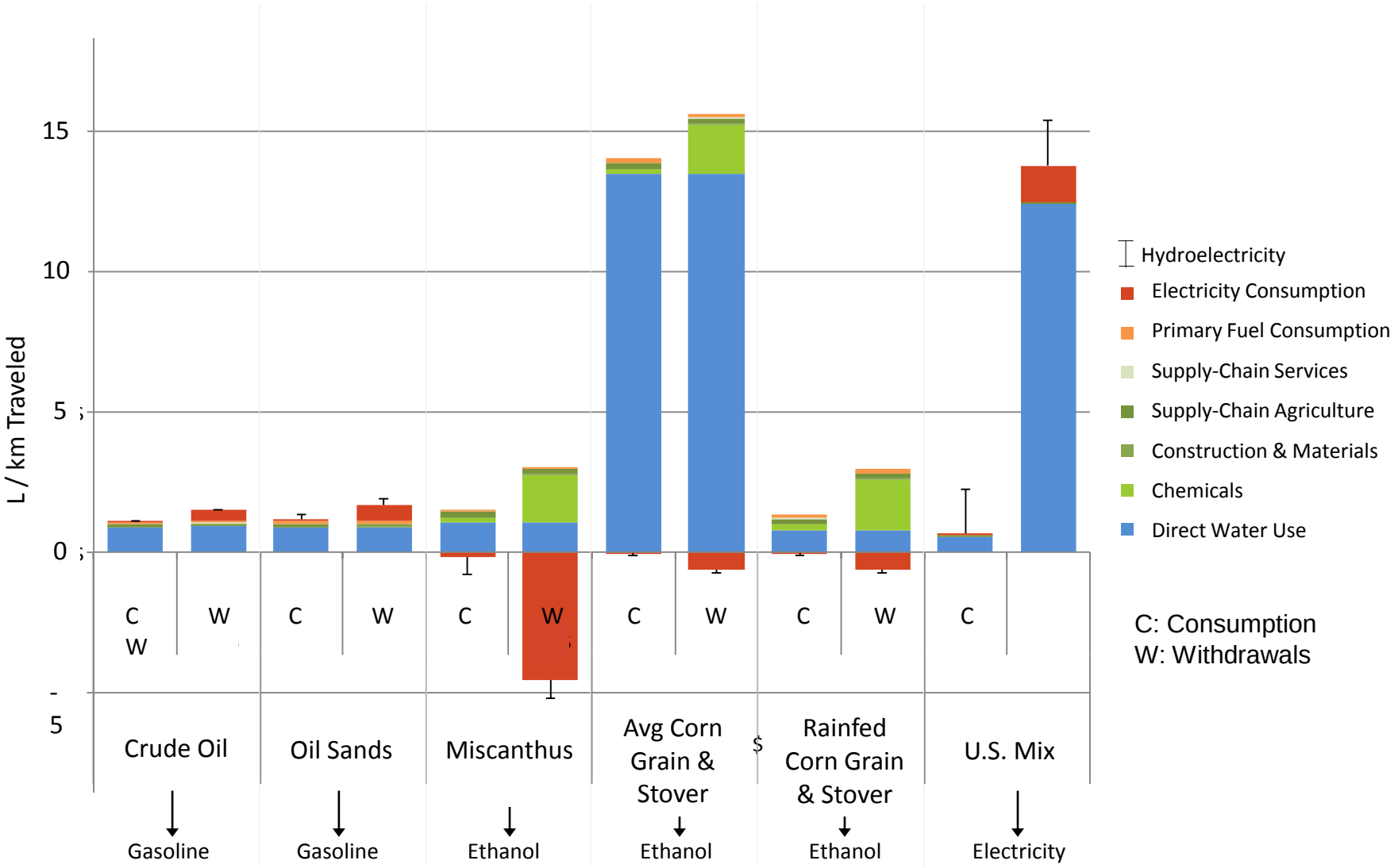
Total Withdrawals – Return Flow



Life-cycle assessment of transportation fuels

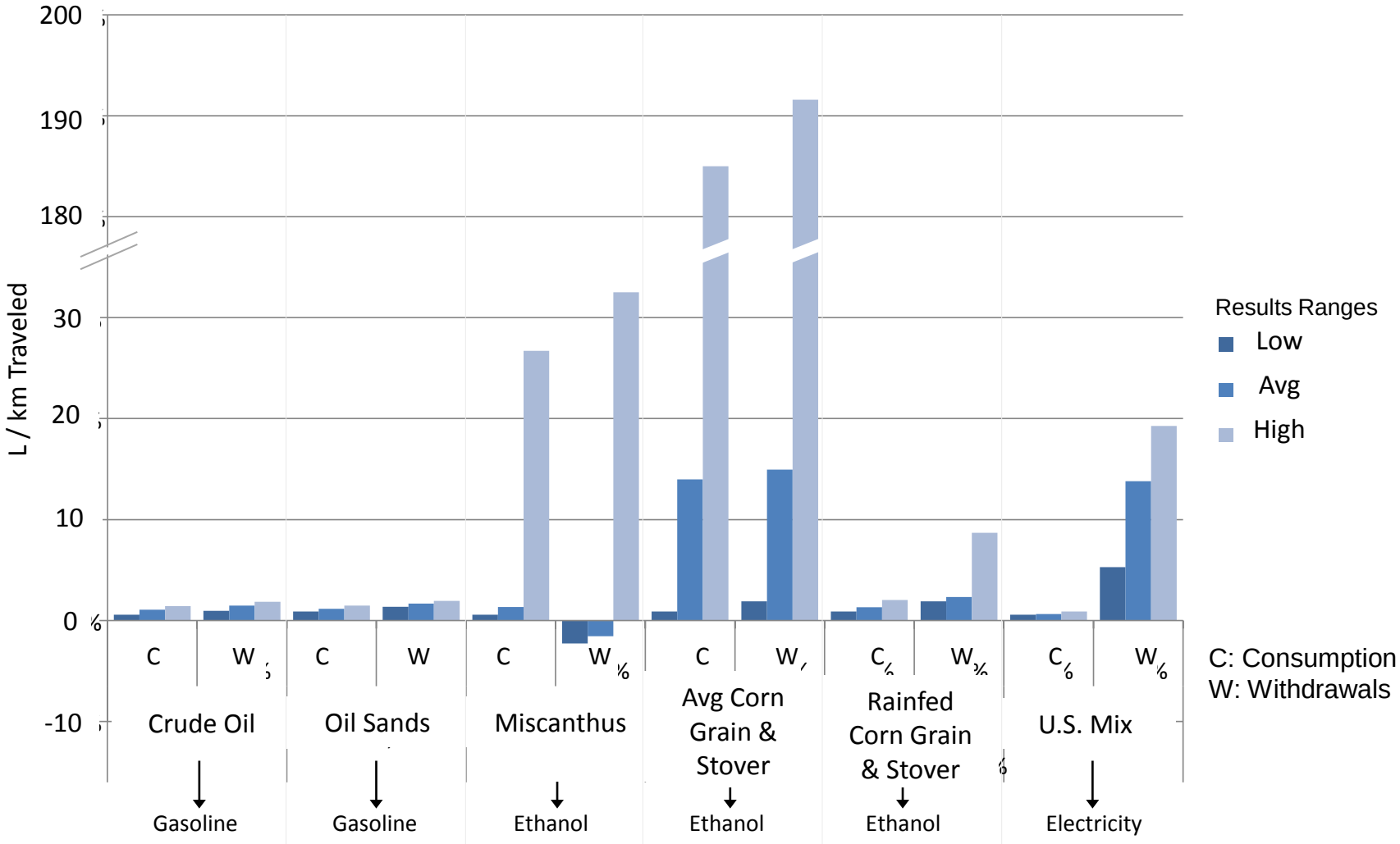
Pathway	Water Consumption	Electricity Consumption	Primary Fossil Fuels	Chemicals	Construction & Materials	Supply-Chain Agriculture	Supply-Chain Services
Crude Gasoline	• Injection water • Refinery process/cooling/other water	• Electricity for extraction, transportation, & refining	• Crude oil • Residual oil • Diesel • Gasoline • Natural gas • Coal • Propane	• Biocides • Surfactants • NaOH • Neutralizers • Inhibitors	• Steel • Concrete • Dust control	• All indirect agricultural sectors	• All service sectors
Oil Sands to Gasoline	• other mining water • Refinery process/cooling/other water	• Electricity for extraction, transportation, & refining	• Residual oil • Diesel • Gasoline • Natural gas • Coal • Propane	• NaOH • Neutralizers • Inhibitors	• Steel • Concrete • Dust control	• All indirect agricultural sectors	• All service sectors
Corn Stover to Ethanol	• Refinery process/cooling/other water	• Electricity for extraction, transportation, & refining	• Residual oil • Diesel • Gasoline • Natural gas • Coal • Propane	• Fertilizers • Glyphosate • Sulfuric Acid • Lime • Corn steep liquor • Cellulase • Diammonium phosphate • Ammonia • Cooling water chemicals • WWT chem		• All indirect agricultural sectors	• All service sectors
Miscanthus to Ethanol	• Irrigation water • Refinery process/cooling/other water	• Electricity for extraction, transportation, & refining	• Residual oil • Diesel • Gasoline • Natural gas • Propane			• All indirect agricultural sectors	• All service sectors
Corn Grain to Ethanol	• Irrigation water • Refinery process/cooling/other water	• Electricity for extraction, transportation, & refining	• Residual oil • Diesel • Gasoline • Natural gas • Coal • LPG	• Glucoamylase • Cooling water chemicals • WWT chemicals		• All indirect agricultural sectors	• All service sectors
Electricity	• Cooling water • Other plant operations water	• Electricity for extraction, transportation, & refining	• Diesel • Natural gas • Coal • Uranium*	Not included	• Steel • Rubber • Concrete • Glass • Sand • Silicon • Primary Fuels	• All indirect agricultural sectors	• All service sectors

Long-term marginal water requirements



Source: Scown C D, Horvath A and McKone T E 2011 Water Footprint of U.S. Transportation Fuels *Environmental Science & Technology* 45 2541–53

Water requirement sensitivity



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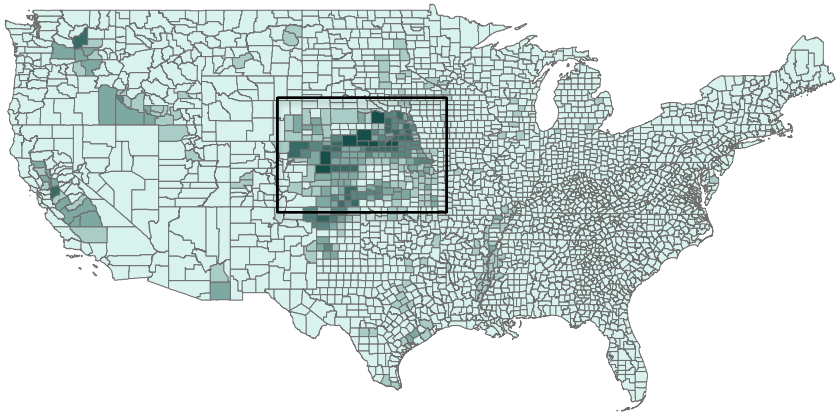
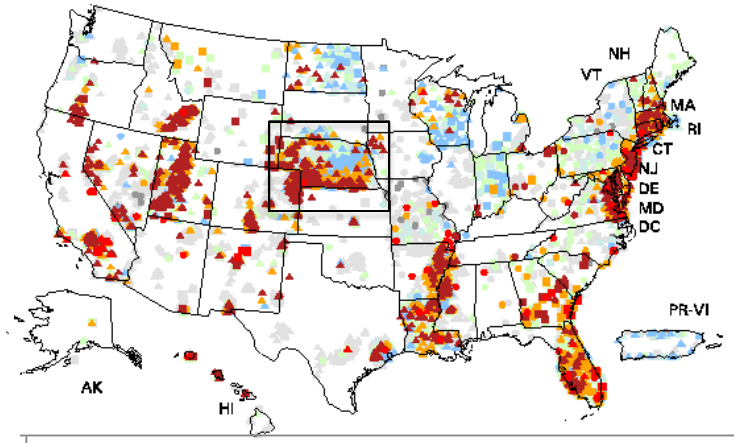
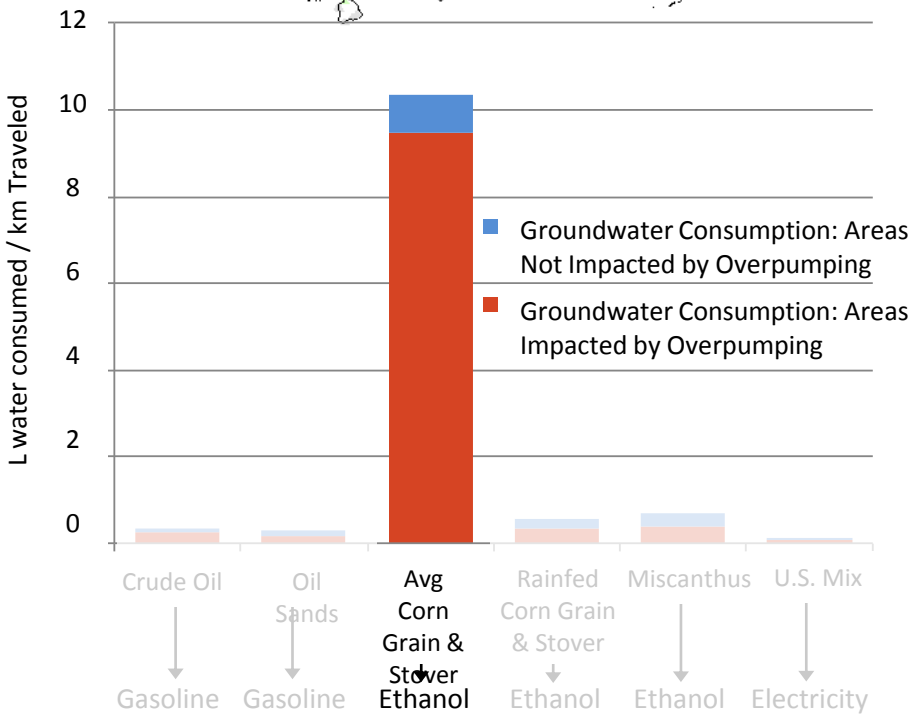
Groundwater





Example: ethanol production from corn grain and stover

Depending on groundwater level measurements and records of subsidence and/or saltwater intrusion, counties are classified as *impacted by overpumping* or *not impacted by overpumping*



Sources: 2010 USGS Groundwater Watch
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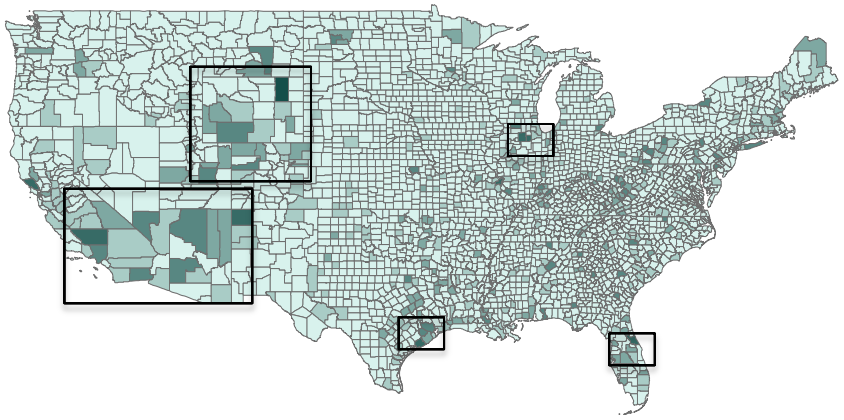
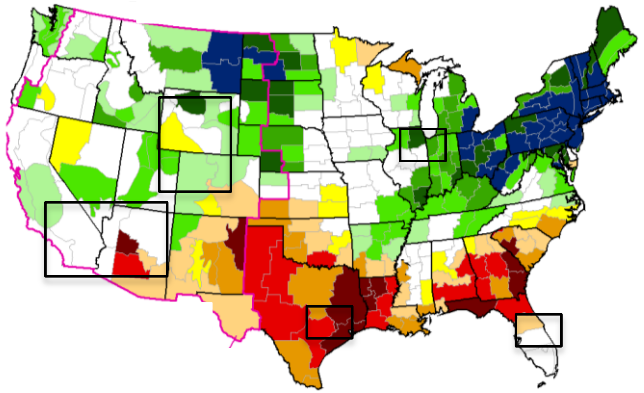
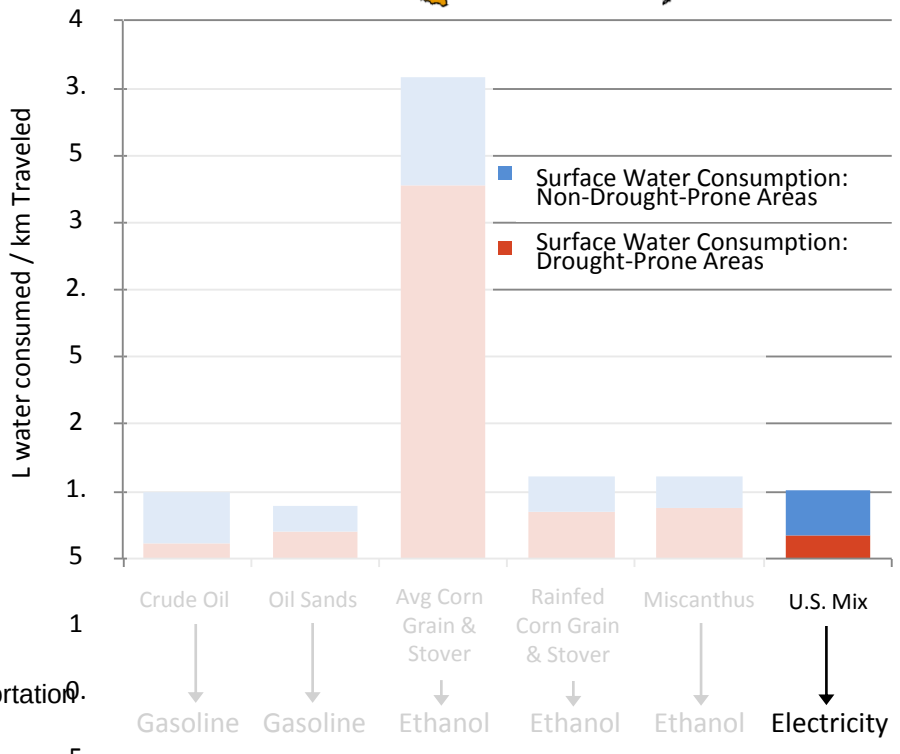
Surface water





Example: surface water consumption for power generation

Depending on historical data and long-term drought predictions, counties are classified as either *drought-prone* or *non-drought-prone*



Sources: US Drought Monitor Objective Long-Term Drought Indices (2011)
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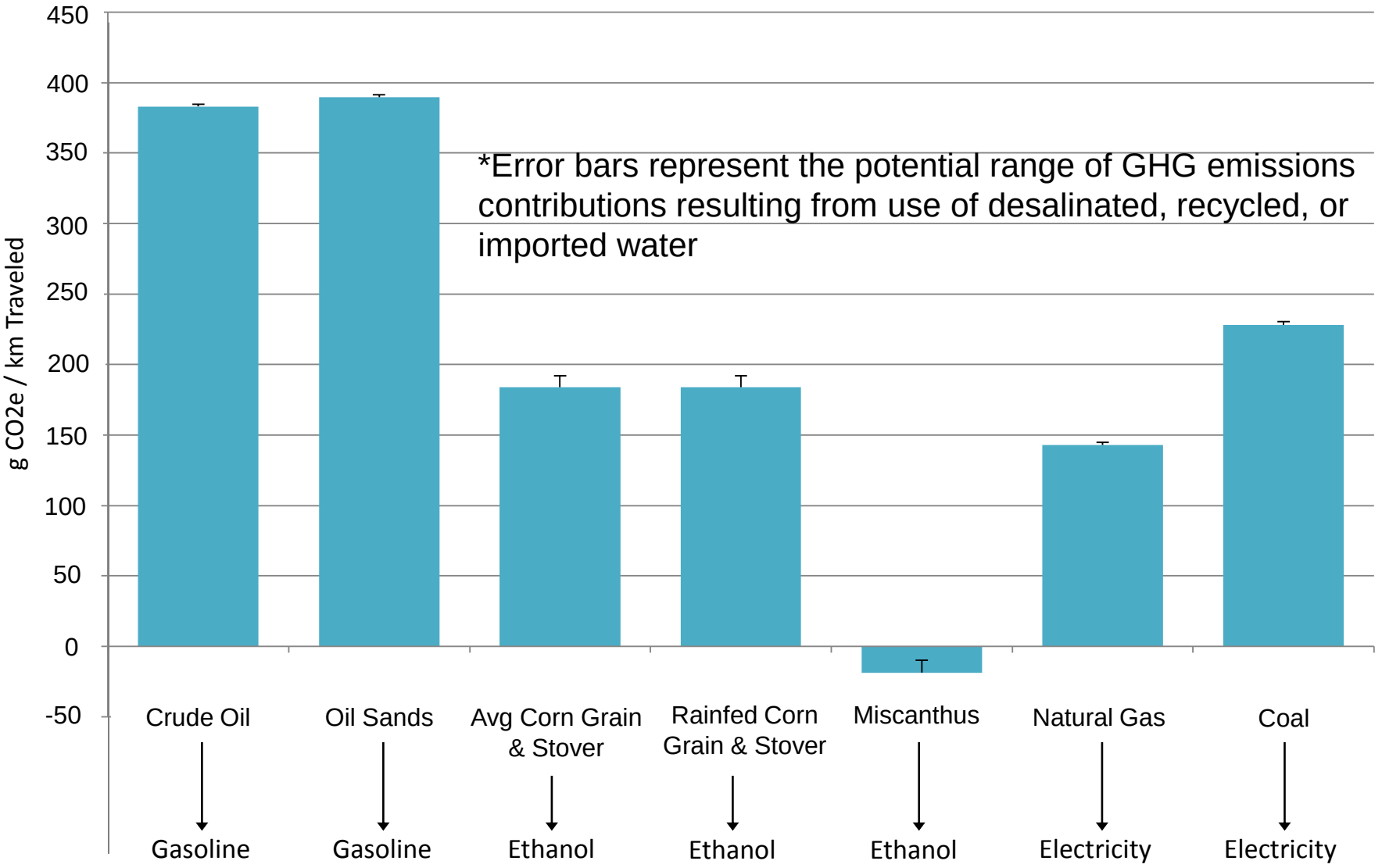
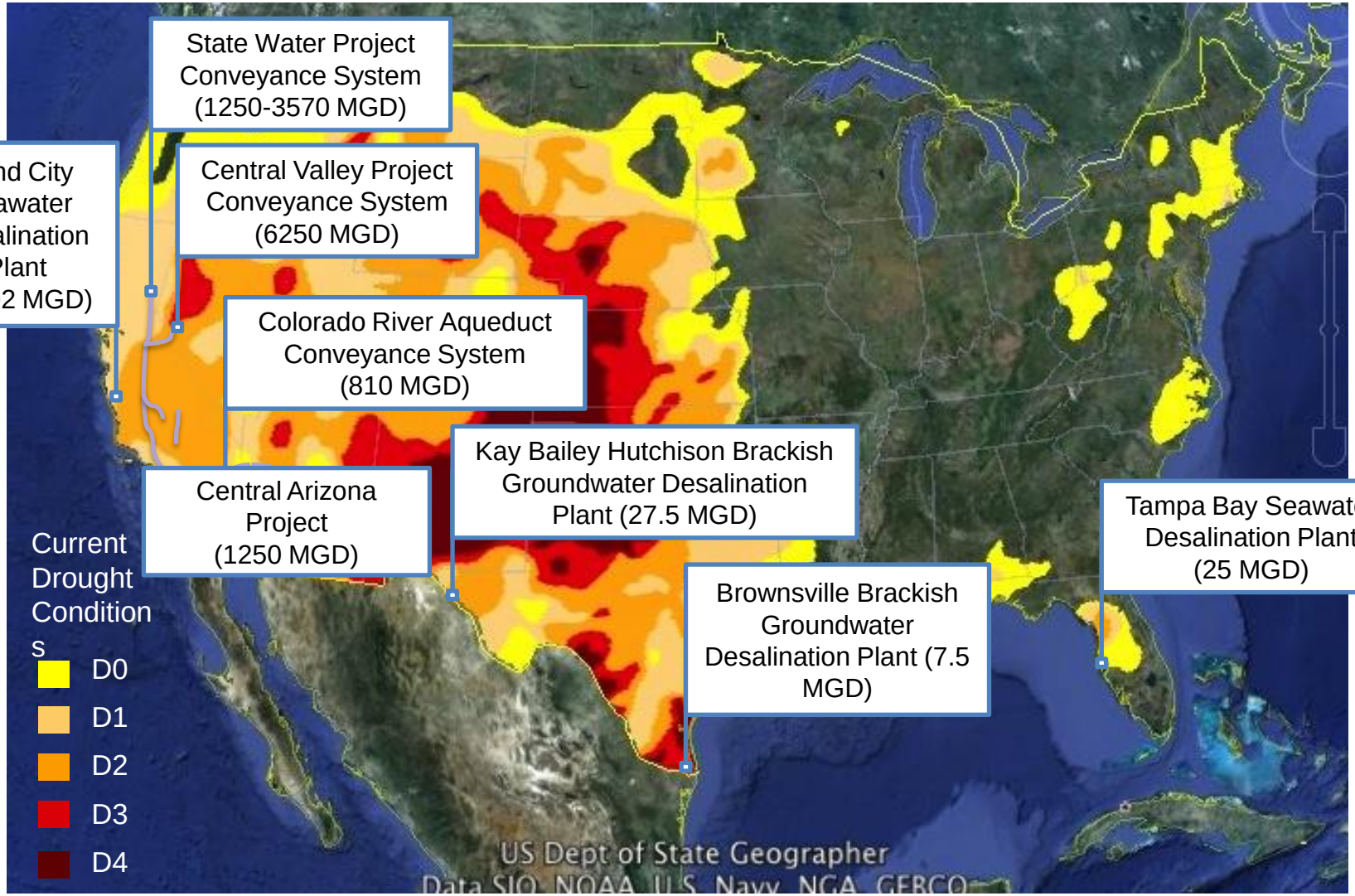
GHG impacts of water supply



Major Energy-Intensive Water Supplies

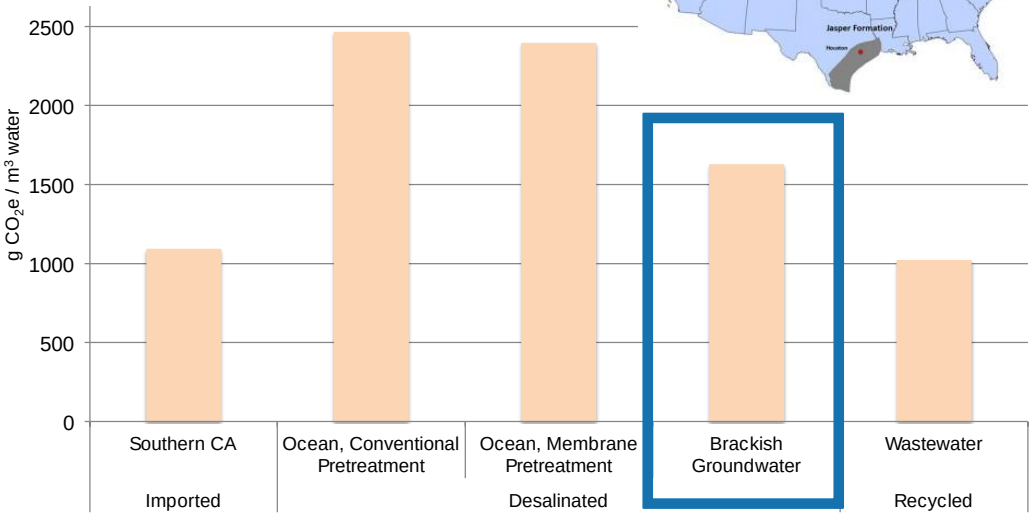


Drought Data: U.S. Drought Monitor May 28th, 2013

GHG-intensity of water supply options

- For all options, electricity generation contributes > 80% of total life-cycle GHG emissions
- Vast majority of remaining GHG emissions are attributable to chemical production

Breunig et al (2013) show that deep aquifers used for CCS may yield saline groundwater suitable for desalination



- California's State Water Project (SWP) is the single largest electricity user in the state, accounting for 6.5% of total power consumption
- Desalinating ocean water to satisfy demand would more than double that demand

Data source: Stokes & Horvath (2009)
Note: recycled wastewater for non-potable uses only

Water-carbon tradeoffs

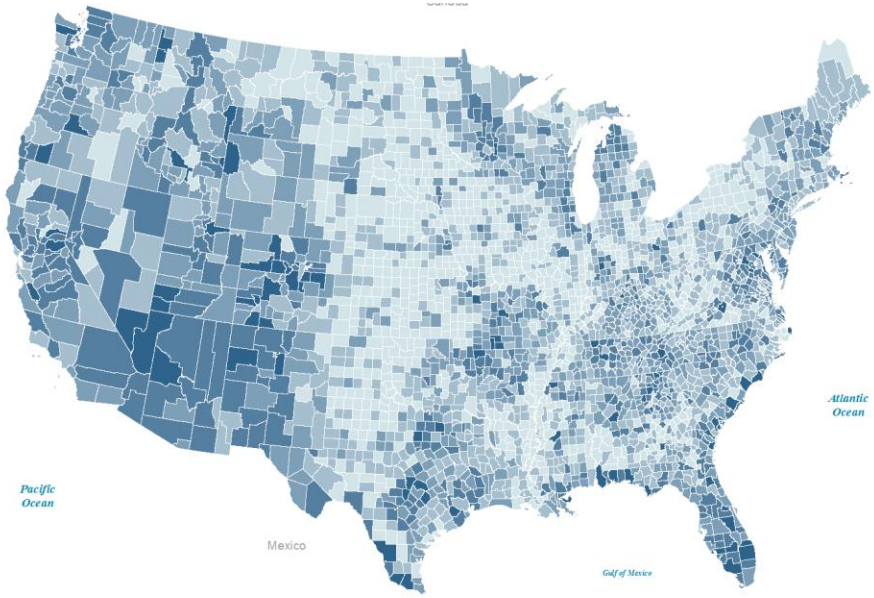
GHG emissions reduction measures do not always reduce water use and vice versa

GHG-saving	Impact on water use	Fresh water saving/producing	Impact on GHGs
Building efficiency	↓	Water-efficient appliances	↓
Vehicle efficiency	↓	Dry cooling at power plants	↑
Trade coal for wind power	↓	Desalination	↑
Trade coal for solar power	↓	Wastewater recycling	↑
CCS at coal plant	↑	Drip irrigation	↓
Trade coal for natural gas power	↓	Increased water recycling for oil & oil sands recovery	↑

Projecting forward

- Agriculture
  - Efficiency likely to increase
  - Effects of climate change will vary by region
  - Dependent on cultivated area & crop choices
- Power generation
  - Withdrawals likely to decrease with fleet turnover
  - Consumption likely to increase
- Public supply
  - Population-driven
  - Water-efficient appliances likely to temper growth

Increasing stress on the west



Projected % change in population (2012-2050)

- -40% - 3.5%
- 3.5% - 26%
- 26% - 51%
- 51% - 84%
- 84% - 330%

Data source: Zarnoch, S. J., et al. (2010)

Some key questions and research needs

- What geographic boundaries are appropriate for co-management of water and energy?

Source: US EPA

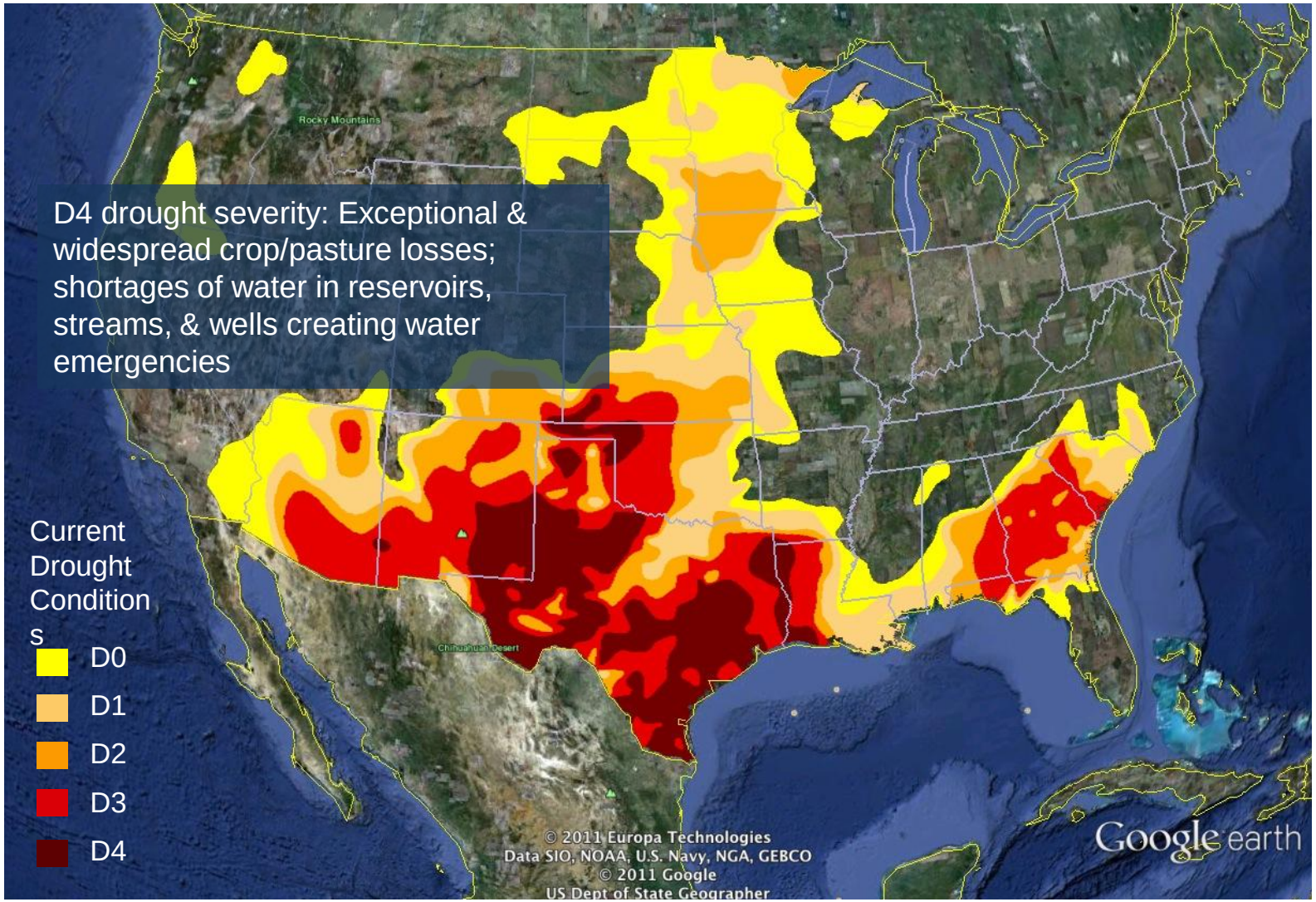
Source: USGS

- How can we balance competing demands for water in droughts: farmers, power plants, industry, public?
- We must gain a better understanding of risks/opportunities associated with energy-related subsurface activities including hydraulic fracturing, CCS, hydrogen storage
- How will climate change affect water needs for power production and agriculture?

Questions?

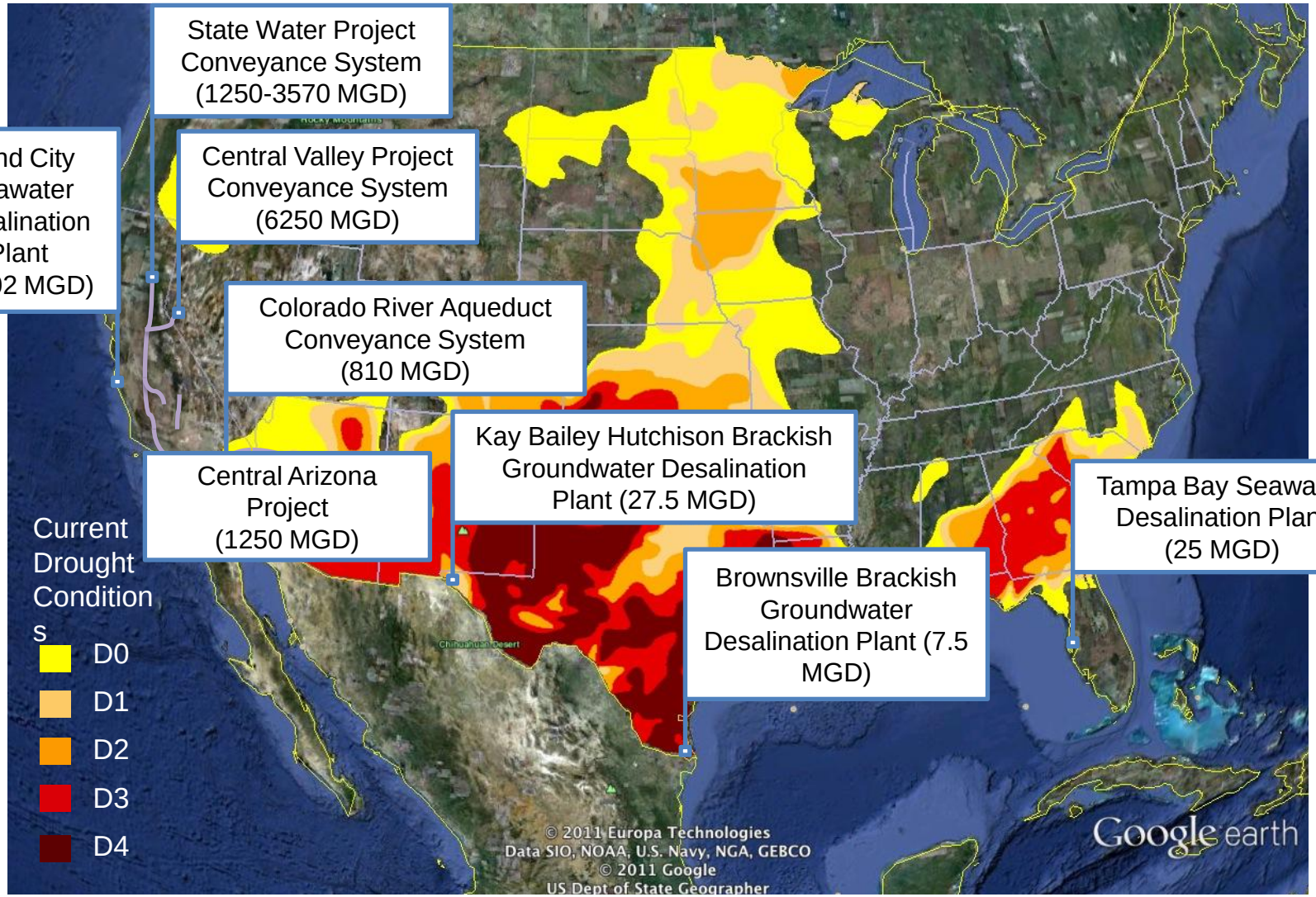
Backup slides

Current Drought Conditions



Drought Data: U.S. Drought Monitor Nov. 29th, 2011

Major Energy-Intensive Water Supplies



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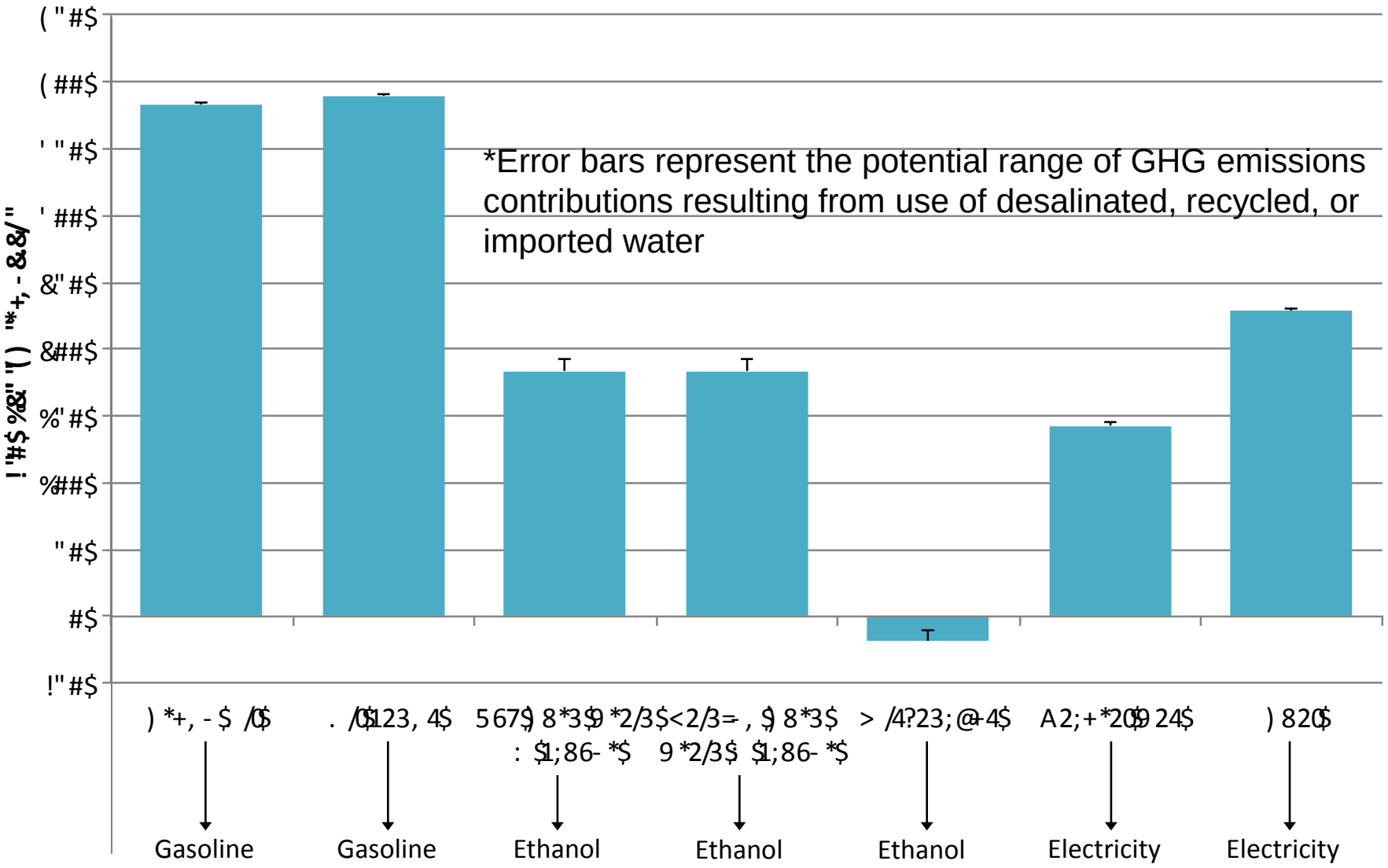

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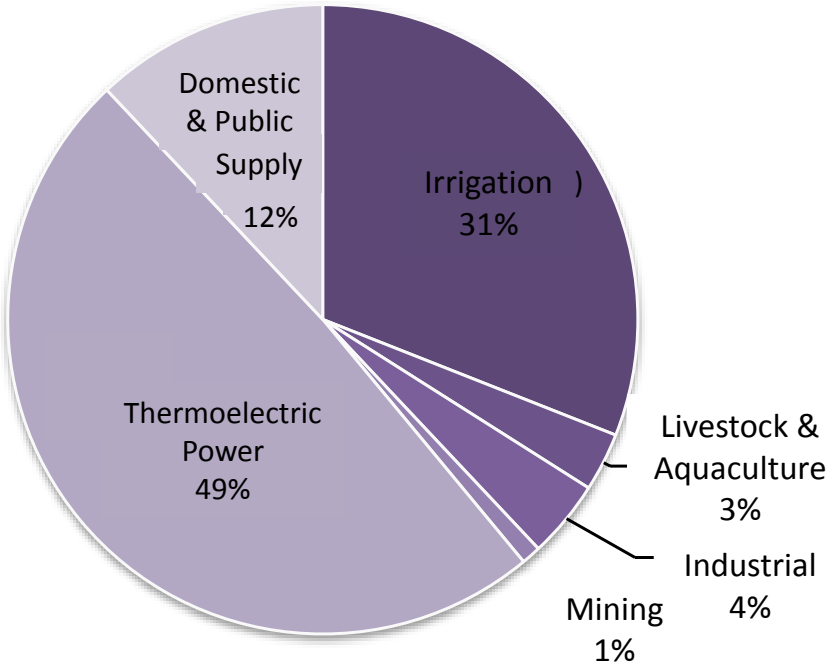
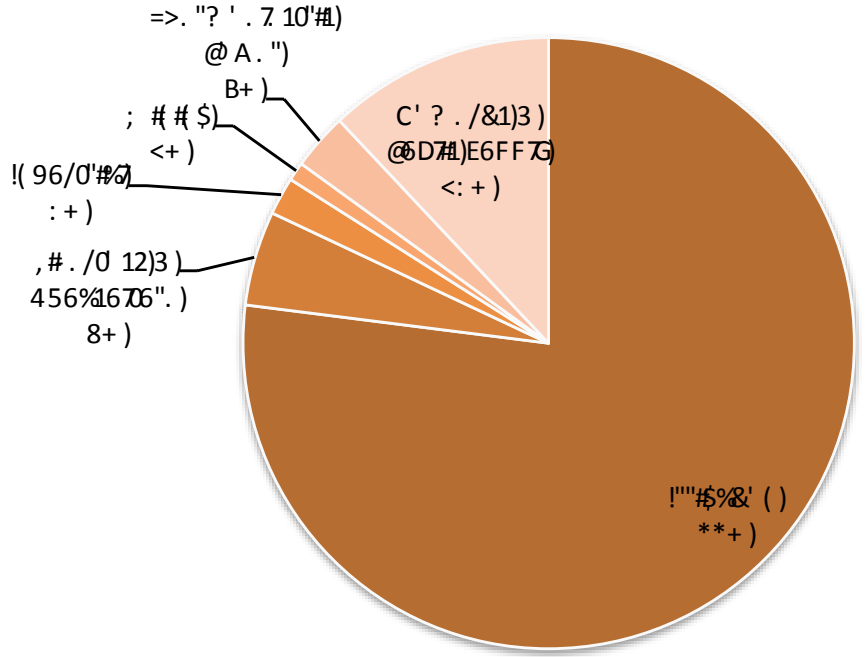
Withdrawals



Consumption



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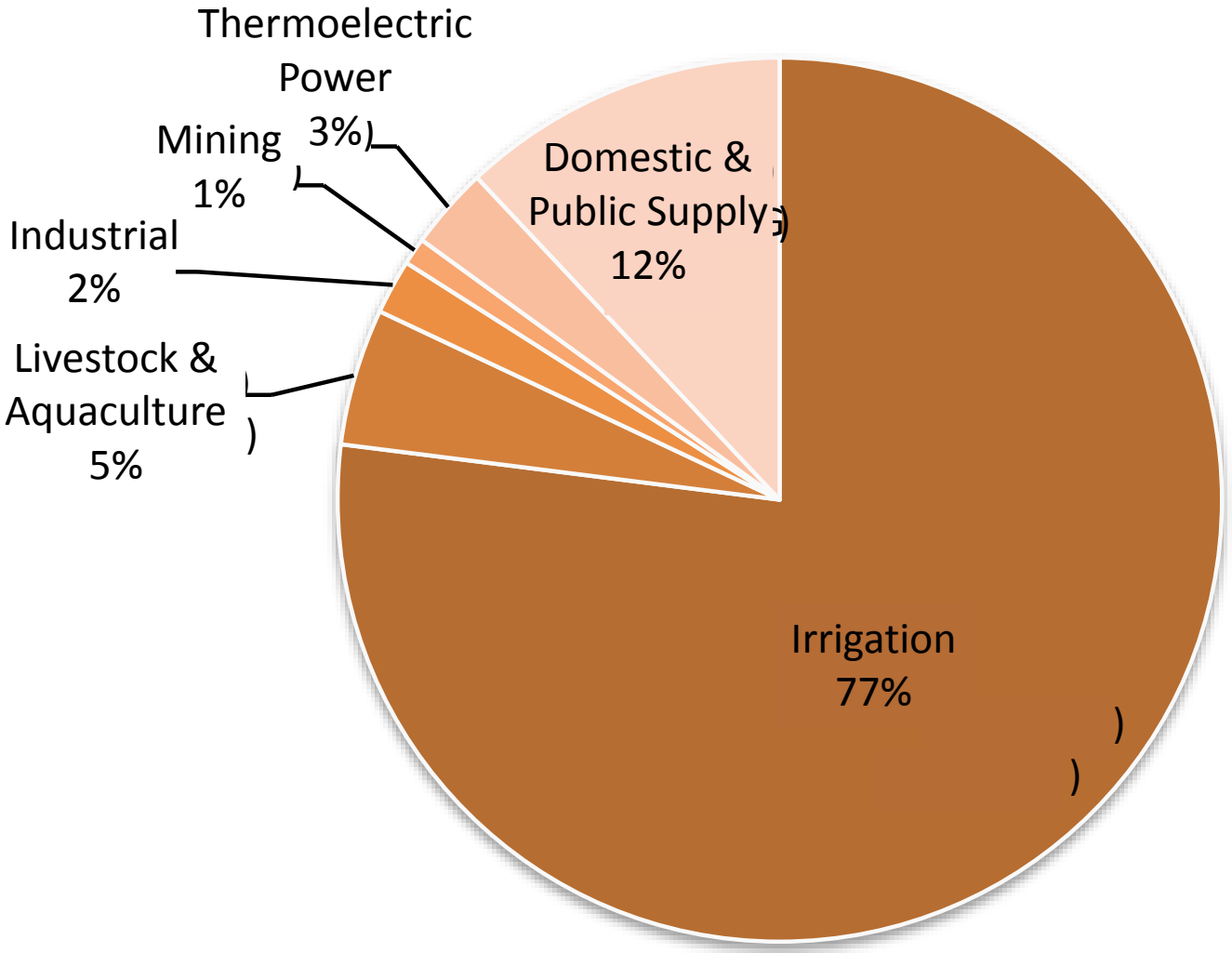
Thermoelectric Power 3%
Mining 1%
Industrial 2%
Livestock & Aquaculture 5%
Domestic & Public Supply 12%
Irrigation 77%