# Driving Sustainability at the Energy-Water-Food Nexus

S-1041 Multistate Committee Annual Meeting

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Partners in Sustainability Integration

# Overview

- What is sustainability?
- Climate change
- Energy
- Water
- Food
- Waste
- Integration
- Prioritizing actions



Shell station at Harris Ranch (Coalinga, CA)

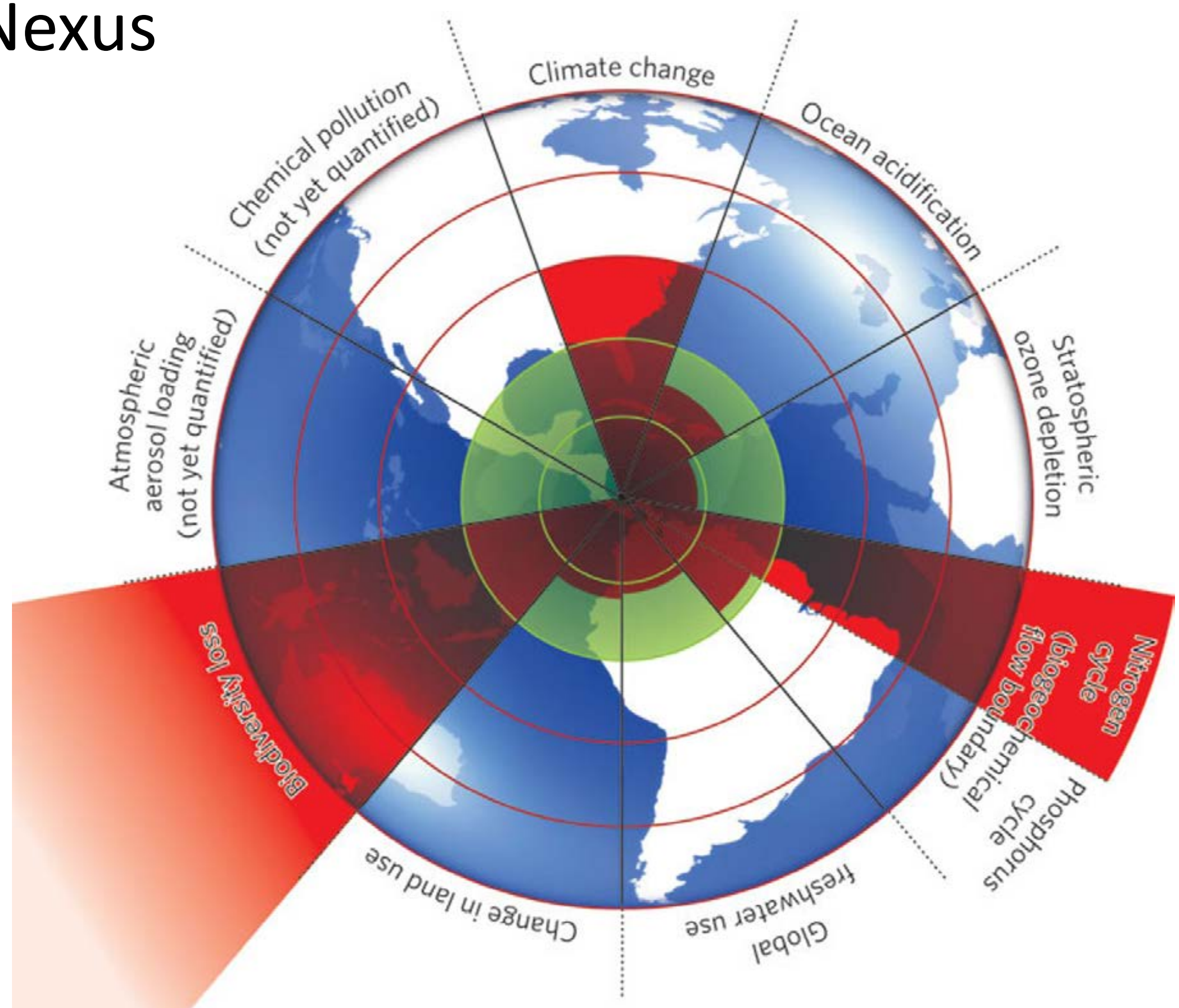
# What is Sustainability?

- All ecosystems are dynamic
  - We cannot prevent some change
  - Change needs to be managed and planned
- Equilibrium
  - Does not mean system is static
  - Balance is achieved
- Mass and Energy Balances
  - Input – output + generation = accumulation
  - Conservation of mass/energy holds across all systems

**Sustainable Development**: to meet the needs of the present without compromising the ability of future generations to meet their own needs. -- Brundtland Commission (1987)

# Global Sustainability

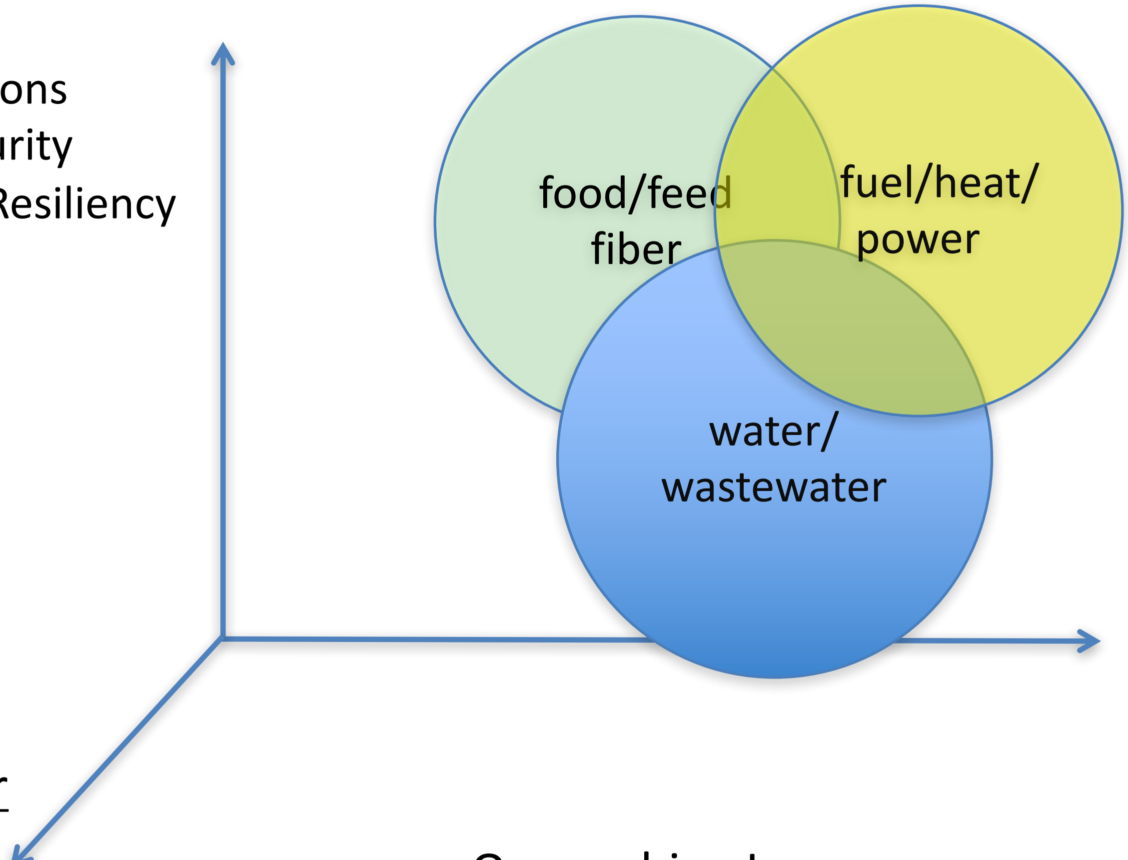
- Water-Energy-Food Nexus
- Supply/Demand
  - – population growth
  - – economic growth
  - – resource availability
  - – climate change




Rockstrom *et al*., A safe operating space for humanity, *Nature*, 2009

# Sustainability Challenges and Opportunities

<u>Energy</u>
- GHG emissions
- Energy security
- Reliability/Resiliency




<u>Water</u>
- Scarcity
- Reliability
- Quality

<u>Food/Feed/Fiber</u>
- Yields
- Land use
- Inputs
- Food security
- Food waste

<u>Overarching Issues</u>
- Climate Change
- Biodiversity
- Eutrophication

# The World in 2050

| Year | $CO_{2e}$ Emissions (GT) | Water Demand $Gm^3$ | Population (billion) |
|---|---|---|---|
| 1990 | 34 | 3600 | |
| 2010 | 46 | | 6.9 |
| 2050 | 6.8 | 5500 | ~ 9.5 |

→ 80% reduction vs. 1990 levels

**Challenges**

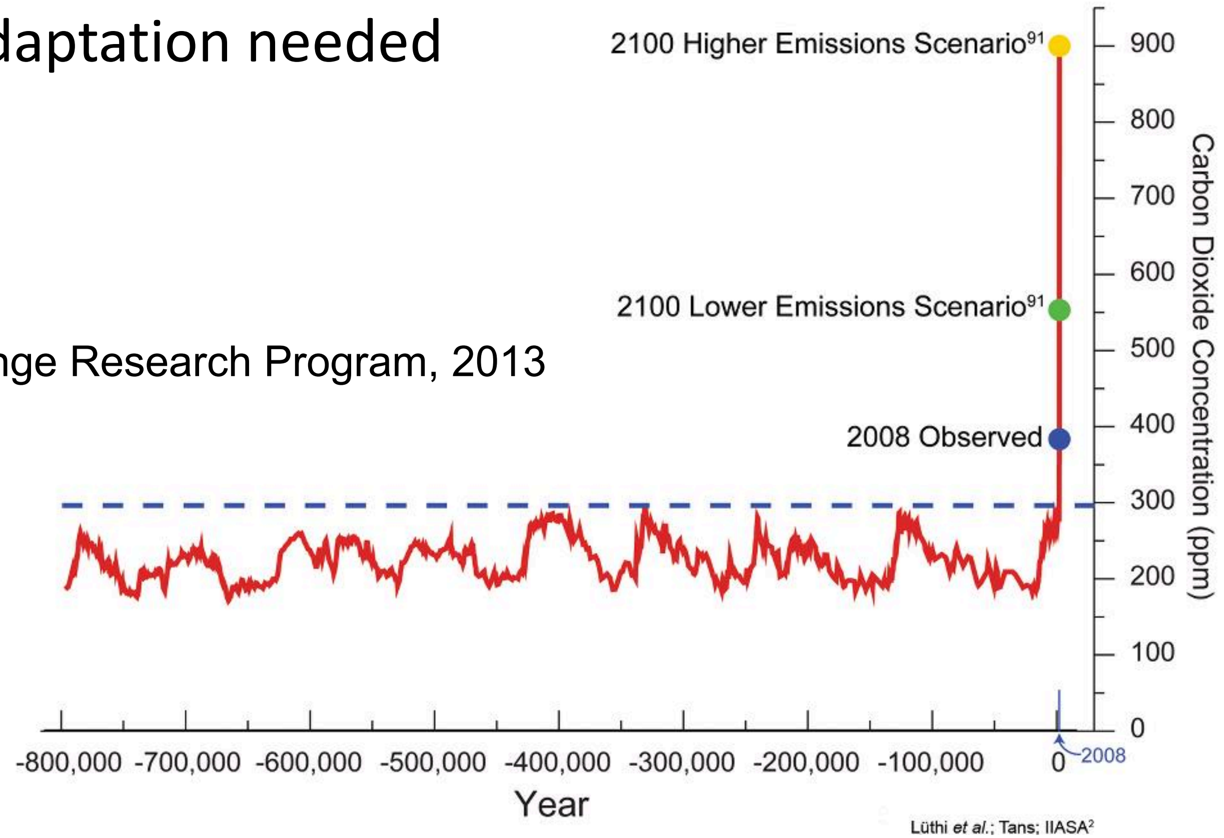
- Will add 2.6 billion people from now until 2050
- Food, energy and water security will be strongly impacted by climate change

Sources: US EPA, OECD, Brookings Inst.

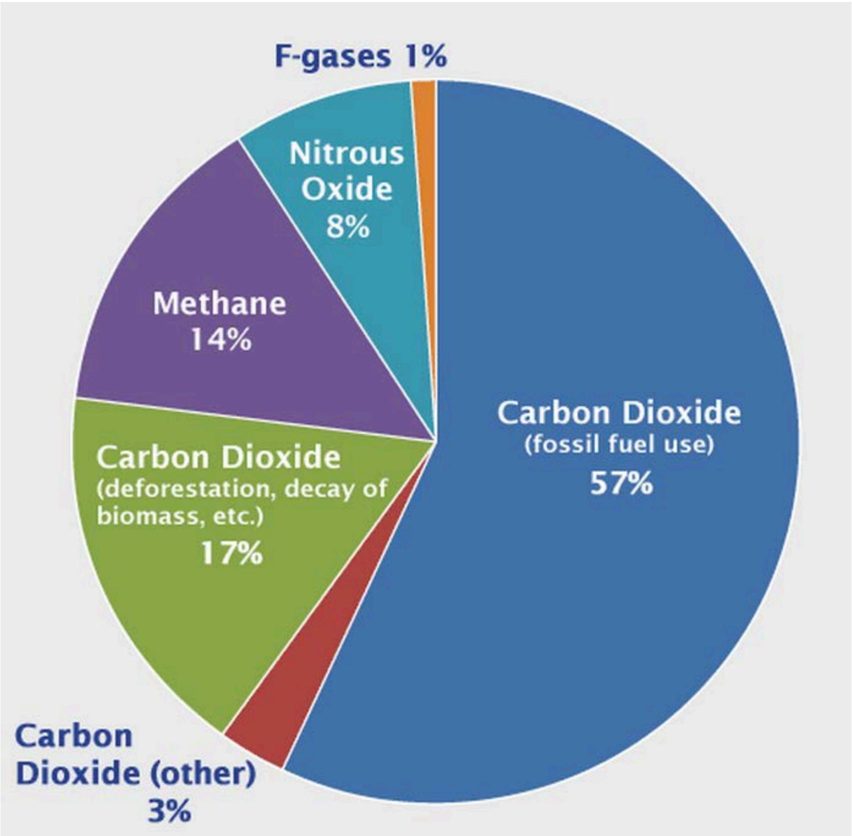
# Climate Security

- World faces huge challenges to stabilize atmospheric GHG concentrations to enable climate security
- Pay now or pay (much more) later
- Mitigation and adaptation needed

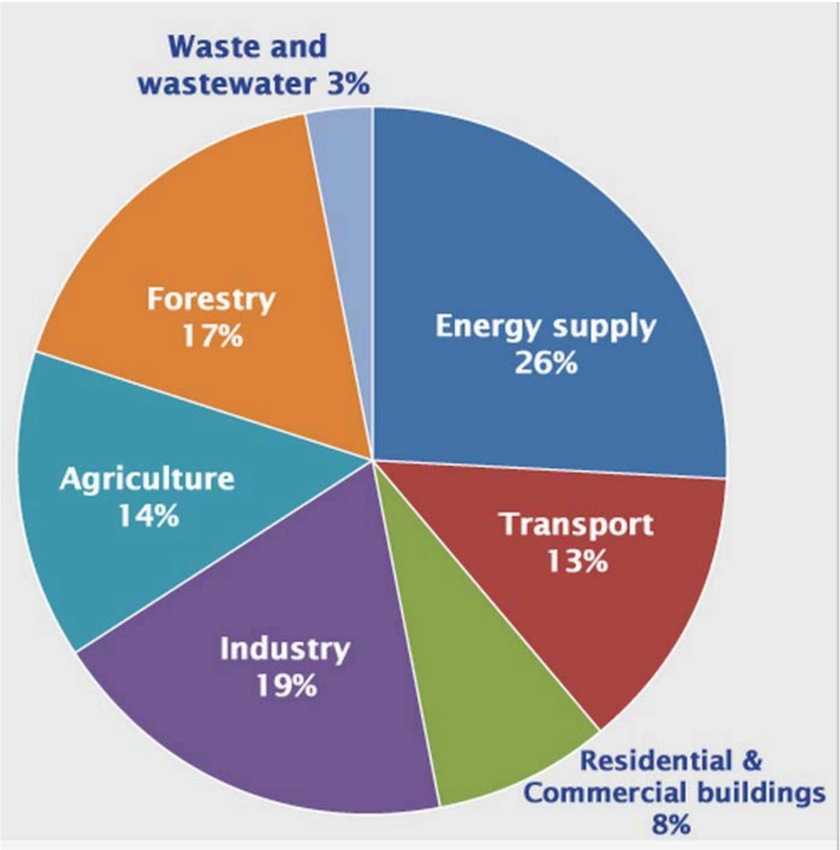
Source: U.S. Global Change Research Program, 2013



# Global GHG Emissions




by gas




by source

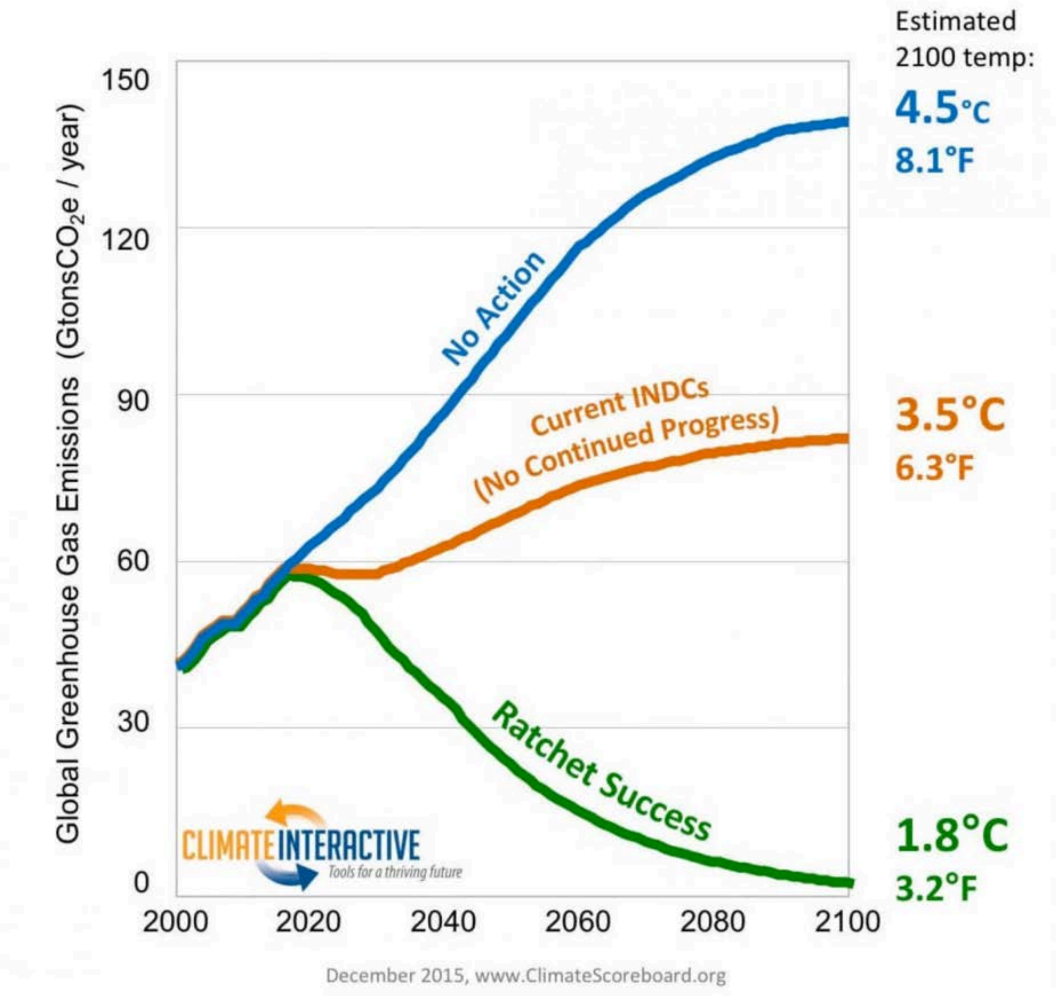
IPCC, 2007

# Methane Emissions


US EPA

# GHG Emissions Path Forward

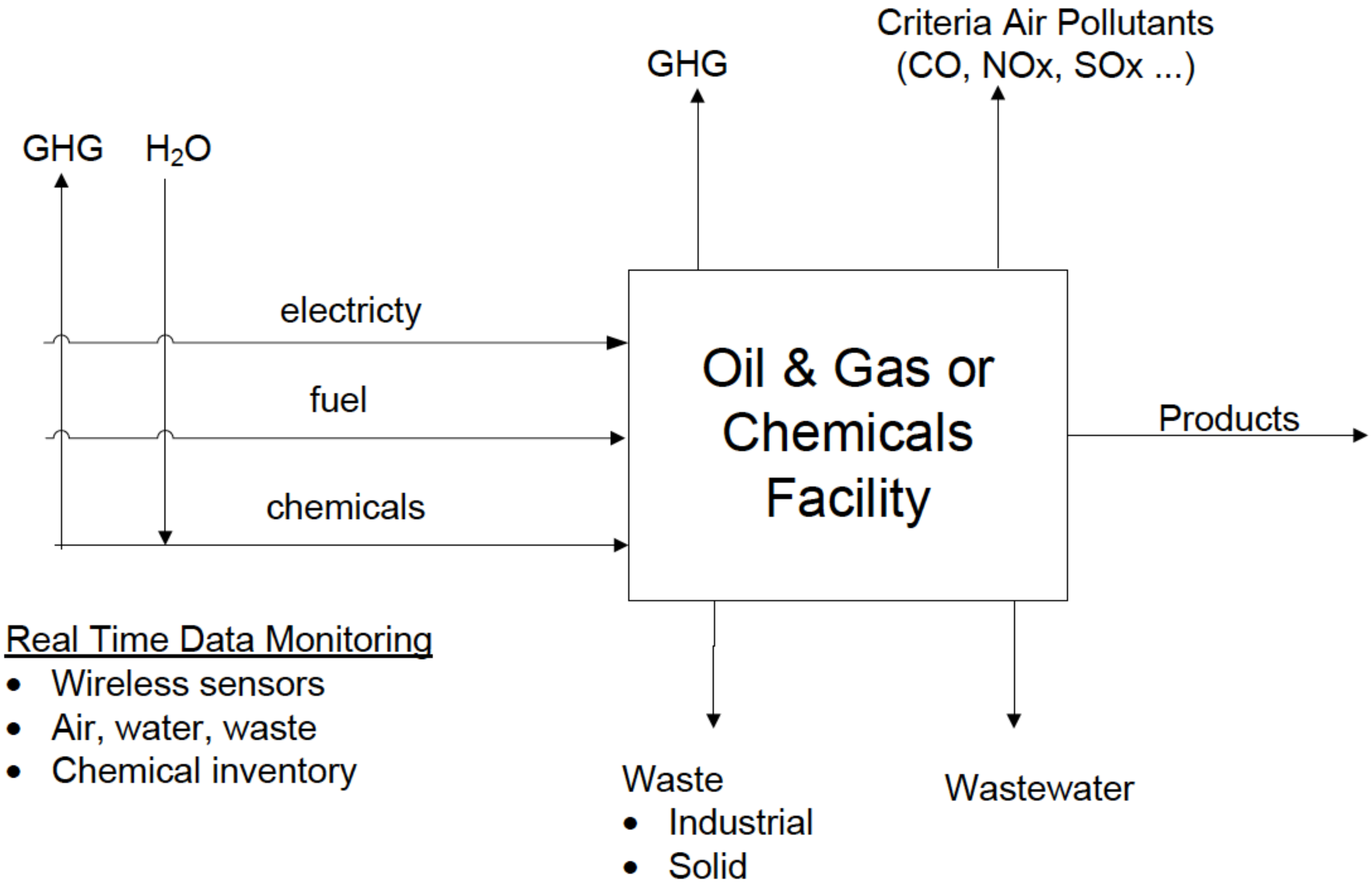
- Current emissions trajectory is 'worst case scenario'
- The agreed-upon target is 2°C warming compared to pre-industrial (we're currently at 0.8°C warming)




Climate Interactive/MIT Sloan

MIT Sloan, 2015

# Next-Generation Processing Facilities




<u>Real Time Data Monitoring</u>

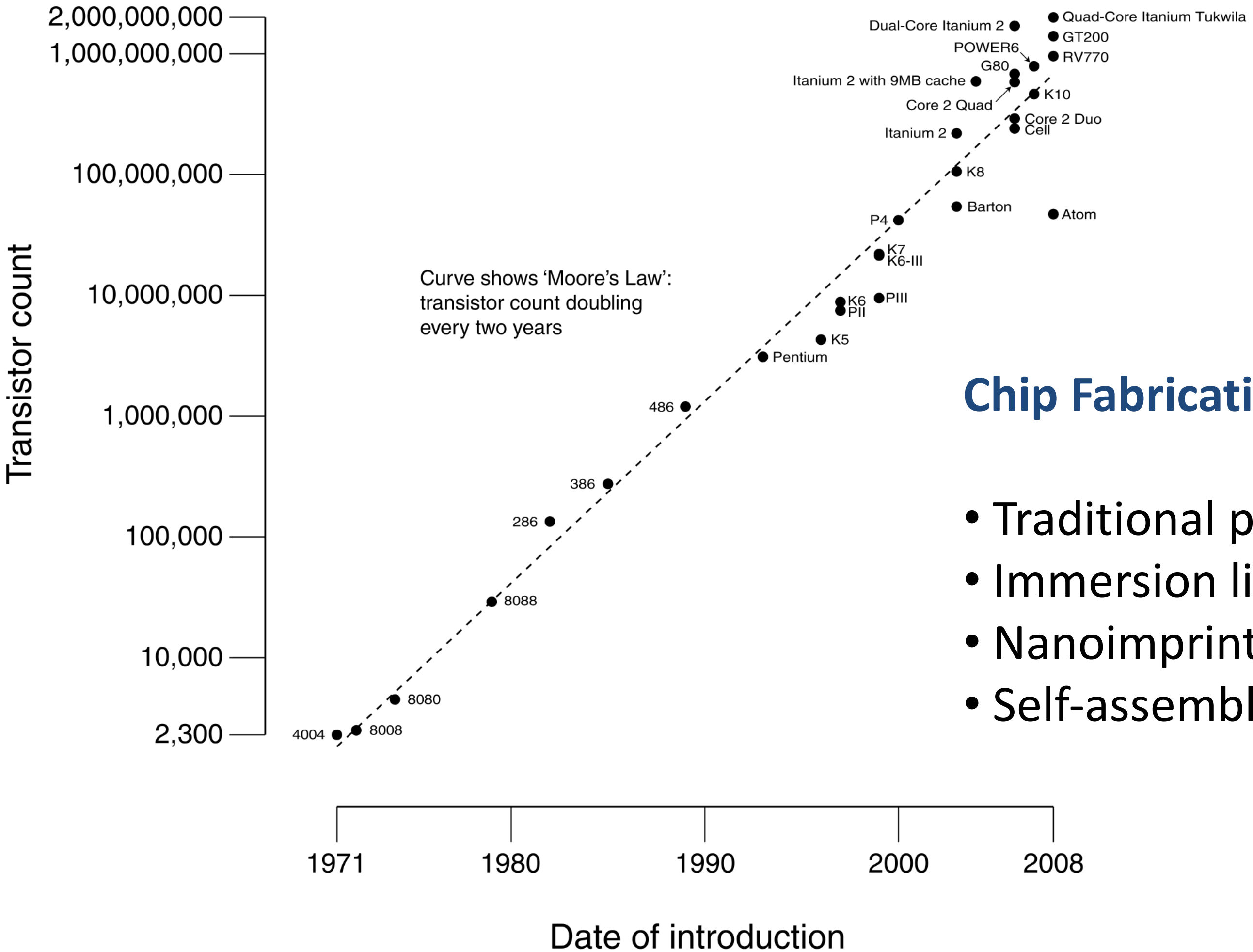
- Wireless sensors
- Air, water, waste
- Chemical inventory

<u>Sustainability Strategies</u>

- Power and heat decarbonization
- Heat and water integration/pinch
- Renewable raw materials
- Waste minimization & recycling

# Power Law Behaviors

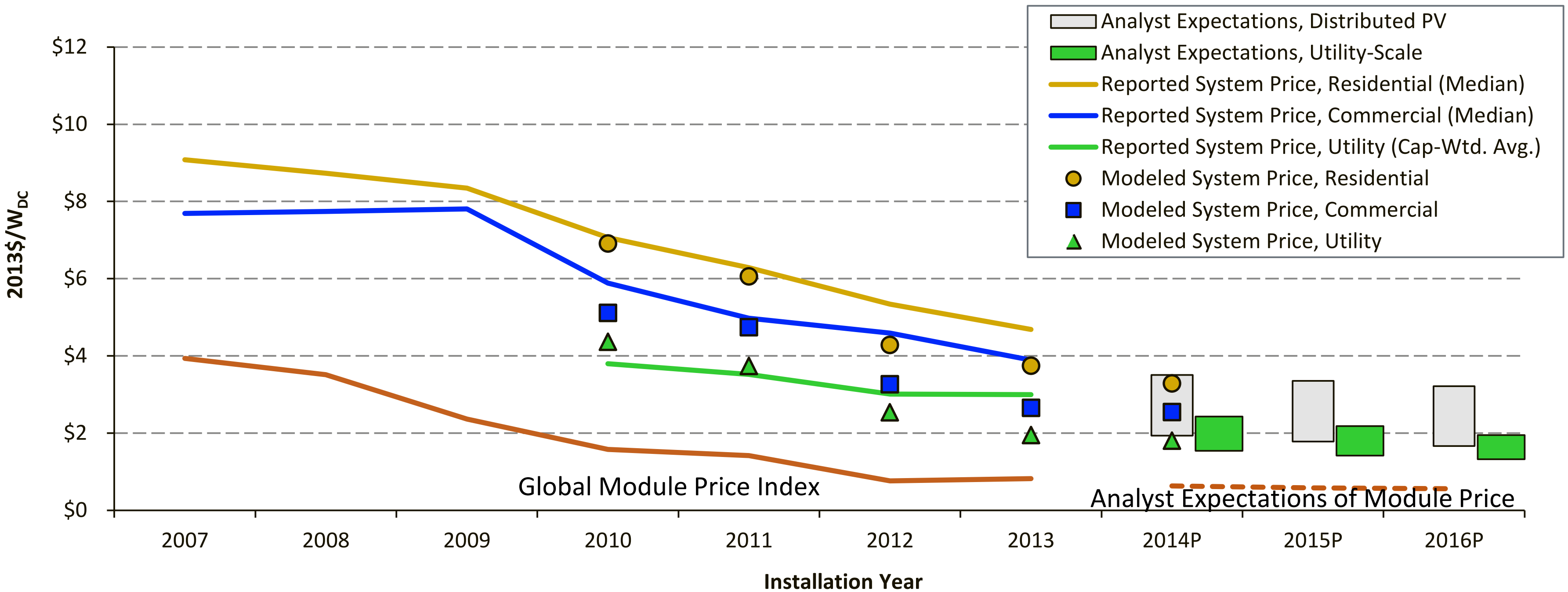
Moore's Law type behavior seen in LED, Solar PV learning curves




## Chip Fabrication Technologies

- Traditional photolithography
- Immersion lithography
- Nanoimprint lithography
- Self-assembling molecular electronics

# Solar PV Price Declines

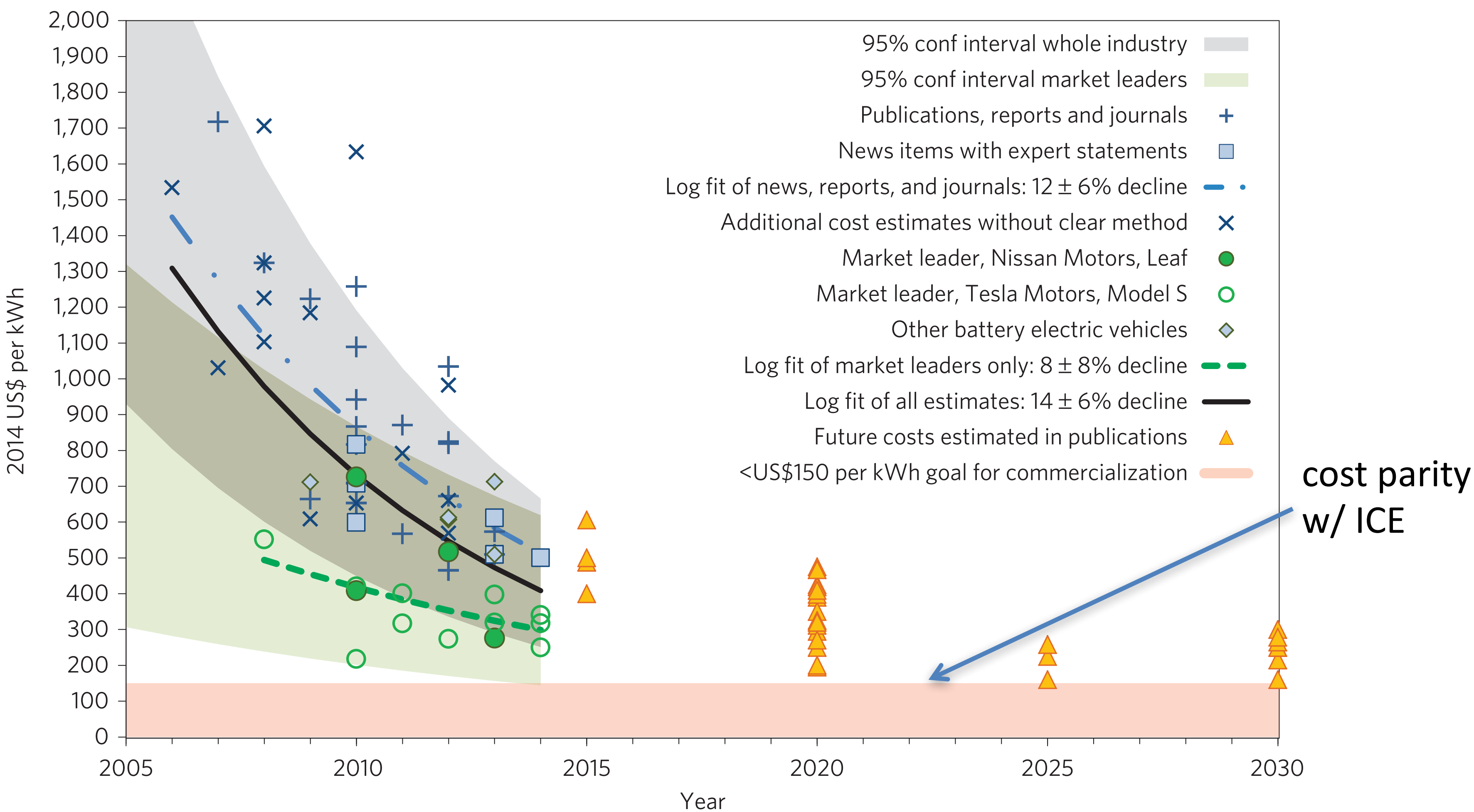



NREL, *Photovoltaic System Pricing Trends*, 2014.

- Innovations in solar financing (e.g. PACE) are making solar more affordable, stimulating demand
- Solar integration w/ energy storage is economically compelling

# Energy Storage

- Battery cost reductions exceeding projections



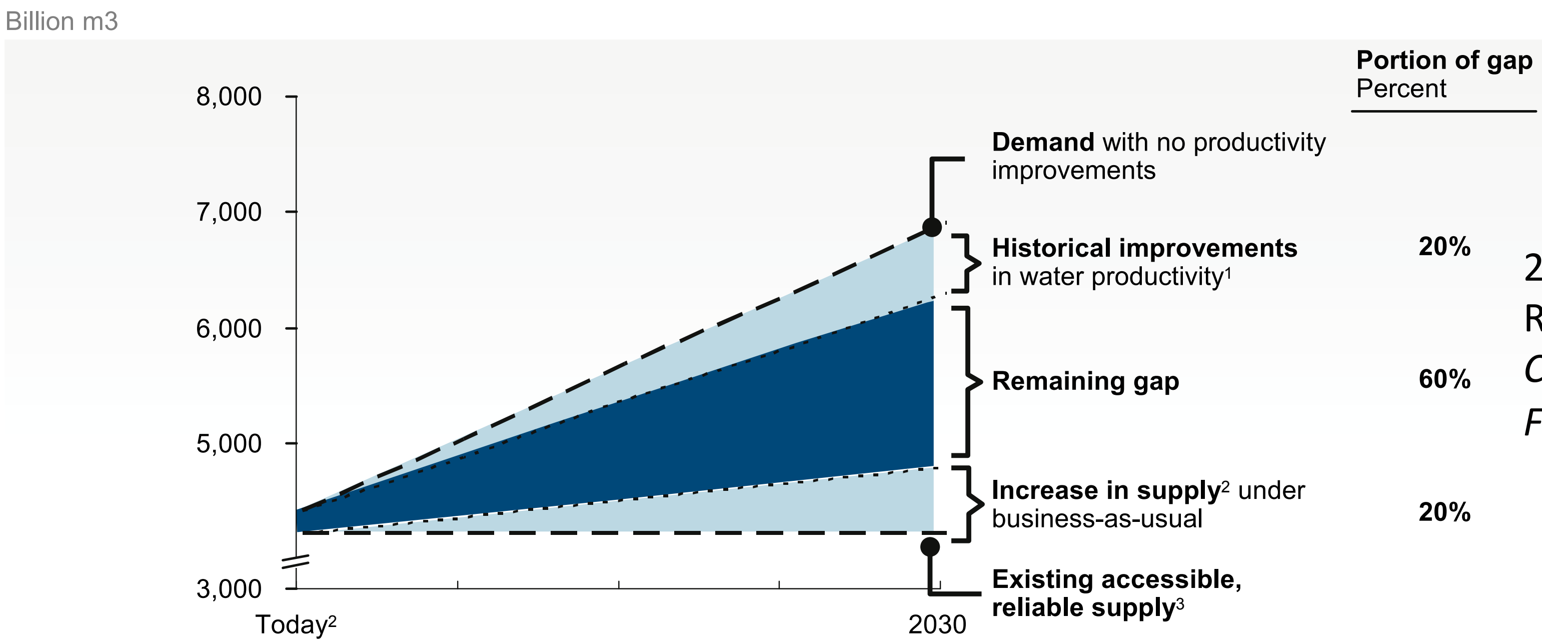

Nykvist and Nilsson, *Nature*, 2015

# Heat and Power Decarbonization

- Solar
  - Thermal
  - Electric
  - Cogen
- Wind
- Bioenergy
  - Biogas
  - Biological conversion of sugars, methane (synthetic biology)
  - Thermochemical conversion
- Geothermal
- Waste heat recovery
- Demand response
- Smart grids

# Water Sustainability

- Water supplies are at risk due to scarcity and degradation of water quality
- Major recent droughts (e.g. Saõ Paulo, California, Madagascar)




2030 Water Resources Group, *Charting our Water Future*, 2009

1 Based on historical agricultural yield growth rates from 1990-2004 from FAOSTAT, agricultural and industrial efficiency improvements from IFPRI
2 Total increased capture of raw water through infrastructure buildout, excluding unsustainable extraction
3 Supply shown at 90% reliability and includes infrastructure investments scheduled and funded through 2010. Current 90%-reliable supply does not meet average demand
SOURCE: 2030 Water Resources Group – Global Water Supply and Demand model; IFPRI; FAOSTAT

# Water Withdrawals & Consumption

- Withdrawal:  water is returned to source watershed
- Consumption: water is evaporated or discharged to another watershed (e.g. ocean outfall)

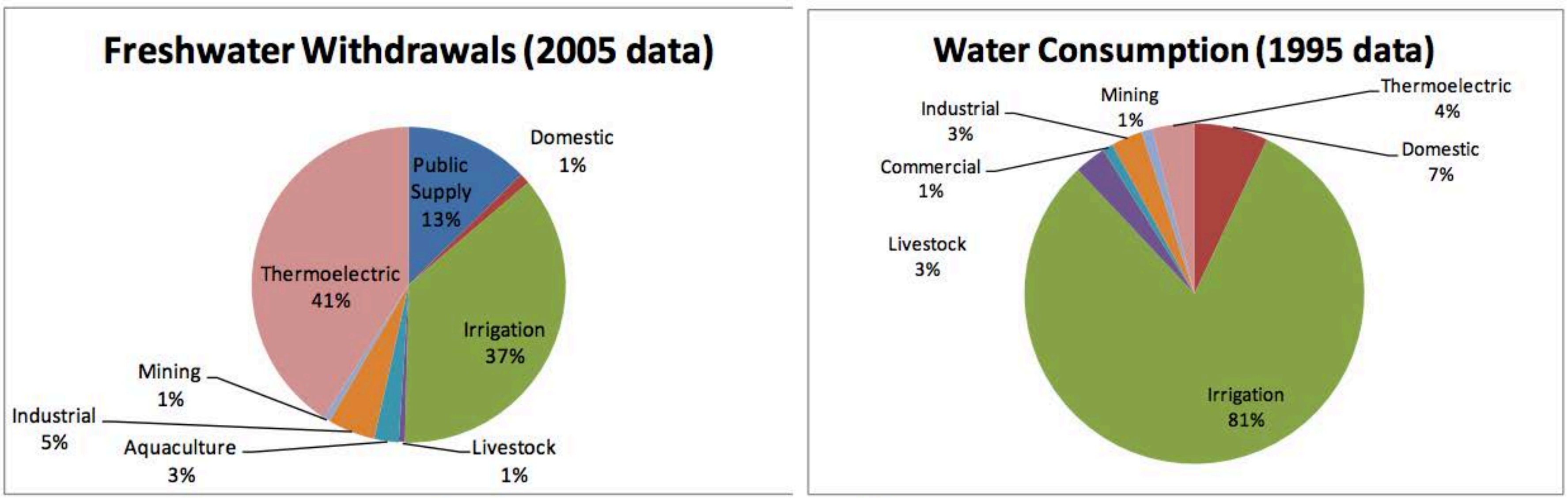



**Figure 1. U.S. Freshwater Withdrawals and Consumption**[1]

Wind and Dums, National Petroleum Council, *Future Transportation Fuels Study*, 2012

# Water Management

- Wastewater treatment
  - Transition to resource recovery facilities
  - Recover carbon, nitrogen, phosphorous
  - Become net-energy producers
- Towards distributed treatment systems (analogous to distributed power generation) – build resiliency
- Water reuse (within facilities and between facilities)
- Brackish water utilization
- Key sectors
  - Ag
  - Thermo-electric power
  - Industry
  - Municipal drinking and irrigation water

cooling tower

# Global Food Demand

**Table 1.1 Key variables beyond 2050**

FAO, 2012

| | 2005/2007 | 2050 | 2080 | 2100 |
|---|---|---|---|---|
| Population (million)- UN 2008 Revision | 6 592 | 9 150 | 9 414 | 9 202 |
| *Population (million)- UN 2010 Revision* | *6 584* | *9 306* | *9 969* | *10 125* |
| **kcal/person/day** | 2 772 | 3 070 | 3 200 | |
| Cereals, food (kg/capita) | 158 | 160 | 161 | |
| Cereals, all uses (kg/capita) | 314 | 330 | 339 | |
| Meat, food (kg/capita) | 38.7 | 49.4 | 55.4 | |
| Oilcrops (oil. equiv.), Food (kg/cap) | 12.1 | 16.2 | 16.9 | |
| Oilcrops (oil. equiv.), all uses (kg/cap) | 21.9 | 30.5 | 33.8 | |
| Cereals, production (million tonnes) | 2 068 | 3 009 | 3 182 | |
| Meat, production (million tonnes) | 258 | 455 | 524 | |
| Cereal yields (tonnes/ha; rice paddy) | 3.32 | 4.30 | 4.83 | |
| Arable land area (million ha) | 1 592 | 1 661 | 1 630 | |

Additional Challenges

- Micro-nutrient deficiency (e.g. anemia) – stunting, IQ penalties
- Land degradation
- Biodiversity, water quality

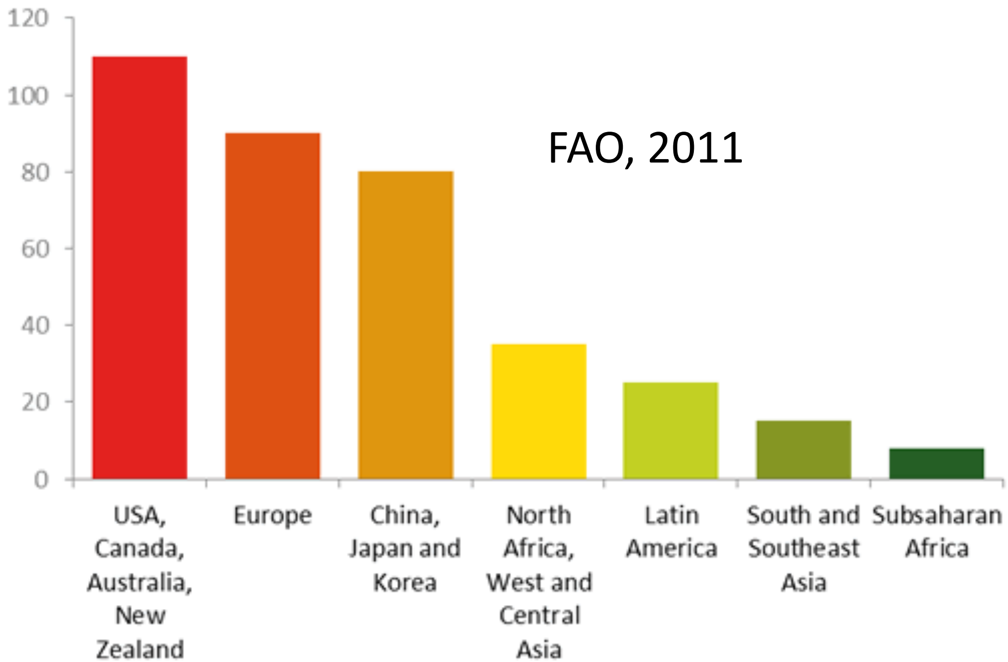
# Food Production

- Advanced crop breeding
- Precision agriculture is reducing use of inputs (water, fertilizer, herbicide, pesticide)
  - Drip irrigation w/ soil moisture sensors
  - GPS control of seeding and input application
- Integration of weather data, forecasting and monitoring of environmental conditions for planning
- Robotics
- Drones
- Adapting practices to minimize GHG emissions (e.g. rice) and improve resilience to changing climates
- Emerging technologies
  - Advanced sensors and information systems
  - Synthetic meat from $CO_2$ to algae/protein

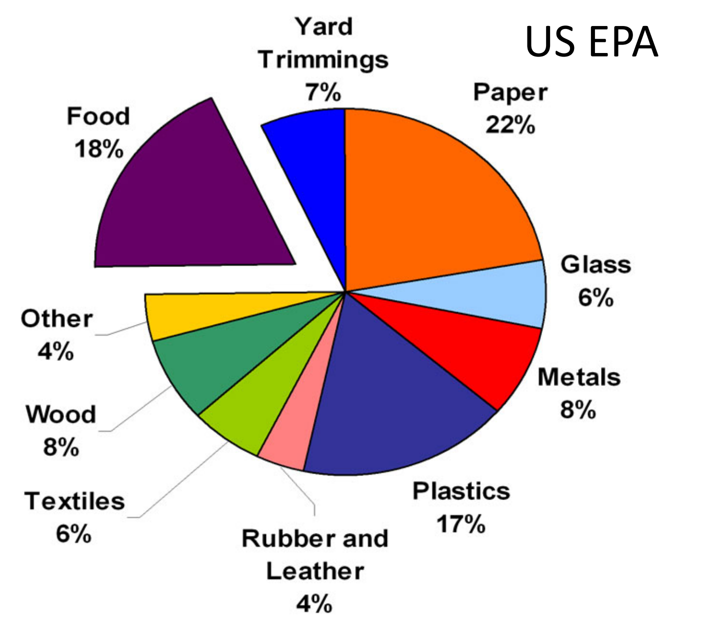
# Food Waste

- Food waste is large source of GHG emissions
- Reduce food waste by:
  - Improved logistics and information access
  - Improved packaging and
  - Better monitoring of thermal history of produce (e.g. RFID tags)

Annual food waste by region (kg/person)




Municipal Solid Waste Sent to Landfill, 2007



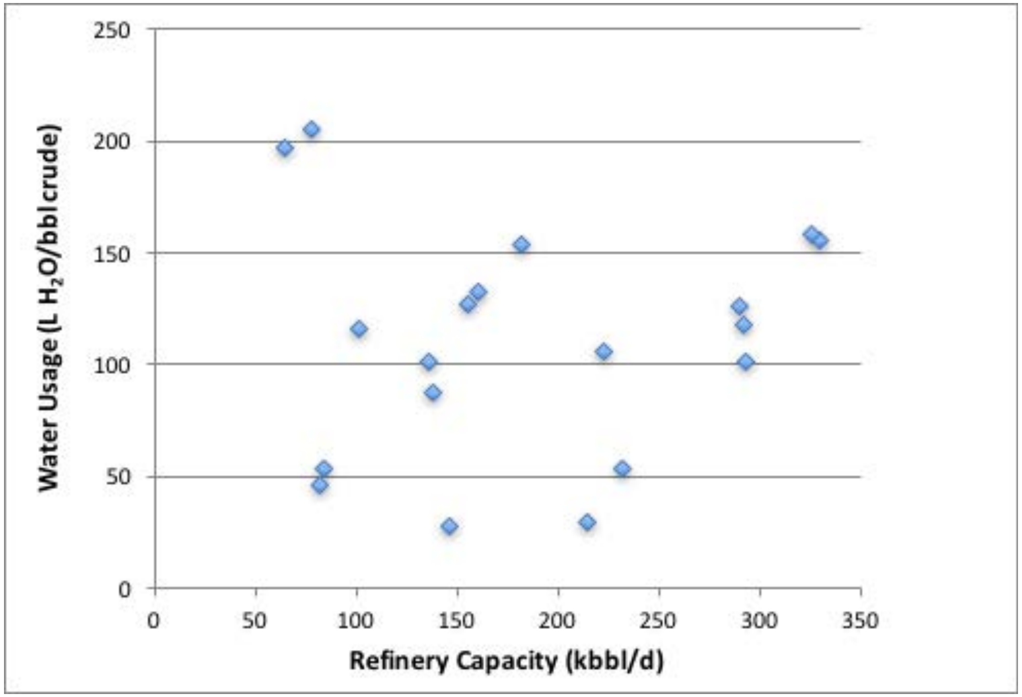
# Waste Management

- Organics: source segregation at household-level vs. organics extraction at transfer facility
- Organics utilization
  - Compost
  - Anaerobic digestion
  - Pyrolysis: bio-crude, bio-char
- Renewable natural gas
  - California has bill on Renewable Gas Standard
  - Anaerobic digestion of organics (food, ag waste, biosolids)
  - Non-intermittent source of renewable energy

See Waste Atlas

# Benchmarking Facility Performance

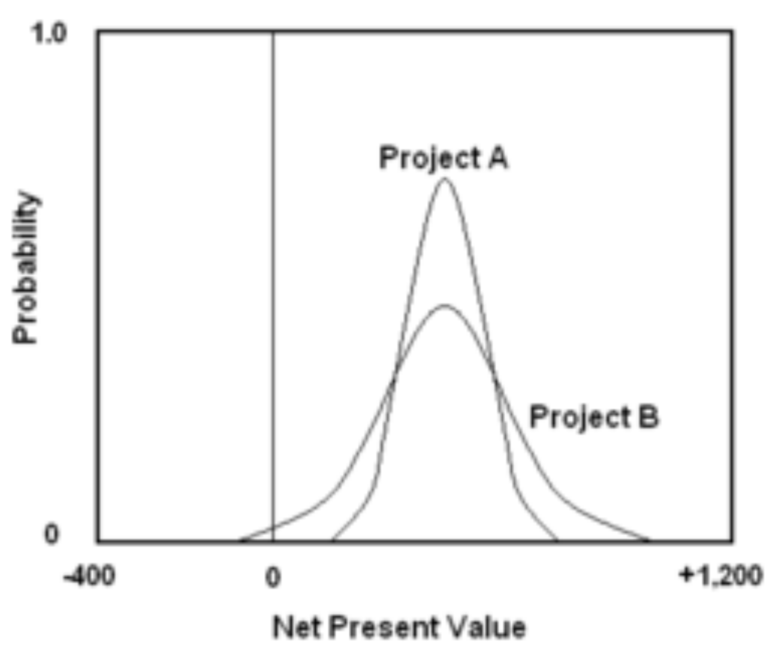
- Benchmark facility performance to determine best in class
  - e.g. Solomon Survey for refineries
  - energy, water, emissions per unit of product output
- Assess best practices for key process units and facility
- Set performance targets to drive improvement and formulate credible plan




Example: petroleum refinery water use (Wind, 2015)

# Ranking Sustainability Investments

- Discounted cash flow analysis to compare investment alternatives
- Probabilistic economic analysis
- Assign value to sustainability metrics
  - Carbon market price and social cost of carbon
  - Value of water (not the cost of water)
- Sensitivity analysis
- Risk analysis




Source: Wikimedia

# Concluding Thoughts

- Process engineering is a useful framework to understand synergies and trade-offs in management of energy, water, food and waste materials
- Systems-level action is critical
- Reducing GHG emissions and water use/consumption can be achieved across all sectors of economy by applying advanced technology and best operating practices
- Improved water management is enabled through recycle, reuse and use of disadvantaged water resources
- Reducing food waste and better utilizing agricultural waste are major opportunities