Sustainability at the Energy-Water-Food-Climate Nexus

AIChe NorCal Symposium
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Overview

- What is sustainability?
- Climate change
- Energy
- Water
- Food
- Waste
- Solutions
  - Digital Decarbonization
  - STEAM Education

Harris Ranch, 2014
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

Energy
- GHG emissions
- Energy security
- Reliability/Resiliency

Food/Feed/Fiber
- Yields
- Land use
- Inputs
- Food security
- Food waste

Overarching Issues
- Climate Change
- Biodiversity
- Eutrophication

Water
- Scarcity
- Reliability
- Quality

Diagnostics
- Scarcity
- Reliability
- Quality
The World in 2050

<table>
<thead>
<tr>
<th>Year</th>
<th>CO$_{2e}$ Emissions (GT)</th>
<th>Water Demand Gm$^3$</th>
<th>Population (billion)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>34</td>
<td>3600</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>46</td>
<td></td>
<td>6.9</td>
</tr>
<tr>
<td>2050</td>
<td>6.8</td>
<td>5500</td>
<td>~ 9.5</td>
</tr>
</tbody>
</table>

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

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

Global GHG Emissions

by gas

- Carbon Dioxide (fossil fuel use): 57%
- Carbon Dioxide (other): 3%
- Methane: 14%
- Nitrous Oxide: 8%
- F-gases: 1%

by source

- Energy supply: 26%
- Forestry: 17%
- Agriculture: 14%
- Industry: 19%
- Transport: 13%
- Residential & Commercial buildings: 8%
- Waste and wastewater: 3%

IPCC, 2007
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)

MIT Sloan, 2015
Next-Generation Processing Facilities

Real Time Data Monitoring
- Wireless sensors
- Air, water, waste
- Chemical inventory

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

LED lighting now displacing kerosene, candles and incandescents in developing countries

Haitz’s Law: every 10 years for LEDs
- price decreases 10X
- flux/unit increases 20X

Additional benefits
- LEDs reducing power consumption for displays (phones, tablets, TV)

Solar PV Price Declines

• Battery cost reductions exceeding projections
• Tesla Gigafactory opened in Reno

Energy Storage

95% conf interval whole industry
95% conf interval market leaders
Publications, reports and journals
News items with expert statements
Log fit of news, reports, and journals: 12 ± 6% decline
Additional cost estimates without clear method
Market leader, Nissan Motors, Leaf
Market leader, Tesla Motors, Model S
Other battery electric vehicles
Log fit of market leaders only: 8 ± 8% decline
Log fit of all estimates: 14 ± 6% decline
Future costs estimated in publications
<US$150 per kWh goal for commercialization
cost parity w/ Internal Combustion Engines

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
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
Data Storage Costs

Free Data in 2017
15 GB (Google)
10 GB (Box)
5 GB (Amazon)
Humans (Maslow, 1943)

• Sustainability: plants need to operate reliably with excellent HES performance in order to optimize
• Optimization conserves energy, water, waste
Convergence of technologies

- Low cost computer processing
- Low cost data storage
- Cloud computing
- Big data analytics
- Python programming language

- Optimization
- Reliability
- Efficiency

- Automation of knowledge work
- Life-cycle asset optimization
Transport Sector Decarbonization

Current Large-Scale

• CAFE standards (lightweighting, turbocharging)
• Biofuels mandates
• CNG (biogas)
• Hybrid Electric, Plug-in Hybrid, Battery Electric Vehicles
• Ridesharing

Emerging technologies

• Mobility as a Service (MaaS) – integrated transport alternatives apps
• V2G (Vehicle-to-Grid) integration
Water Sustainability

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

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 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
Water-Climate Nexus in California

• 2011-2016
  – Extreme/Exceptional Drought
• 2017
  – Record precipitation
  – 560” snow at Kirkwood Ski Resort
  – Oroville Dam spillway breach
• Direct Potable Reuse
• Climate change and water: some specific issues
• California: exceptional drought to record precipitation, Oroville Dam example
  – Atmospheric rivers and climate change
  – Subsidence, groundwater overdraft
  – Groundwater storage (aquifer recharge)
• Climate change and air quality (e.g. ozone, PM2.5)
Food Waste – Major Opportunity

• Food waste is large source of GHG emissions
  – Labeling changes in U.S.

• 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)

US EPA

Municipal Solid Waste Sent to Landfill, 2007

FAO, 2011
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
• Automation and Artificial Intelligence (AI) will radically transform the U.S. and global economies

• Social and economic impacts
  – Supply/Demand balance for labor
  – Social stability

• Advanced manufacturing opportunities
  – Deep decarbonization
  – Water conservation
  – Minimal waste generation & emissions
STEAM Education

• We have an educational crisis in the United States
• Betsy DeVos will make things worse
• Partners in Sustainability Integration is working with Olimpico Learning on STEAM education in Richmond and Oakland
• Benefits of STEAM
  – Rebuilding an informed society
  – Develop skills to *actually* make America great, a *real* leader
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 can be achieved across all sectors of economy by applying advanced technology and best operating practices
• A Golden Age of chemical engineering may be emerging due to advanced computing and automation capabilities