DIRE-FEWS

DIsaster REsilient Food Energy Water Systems

An Imperative for STEM Education

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Biography

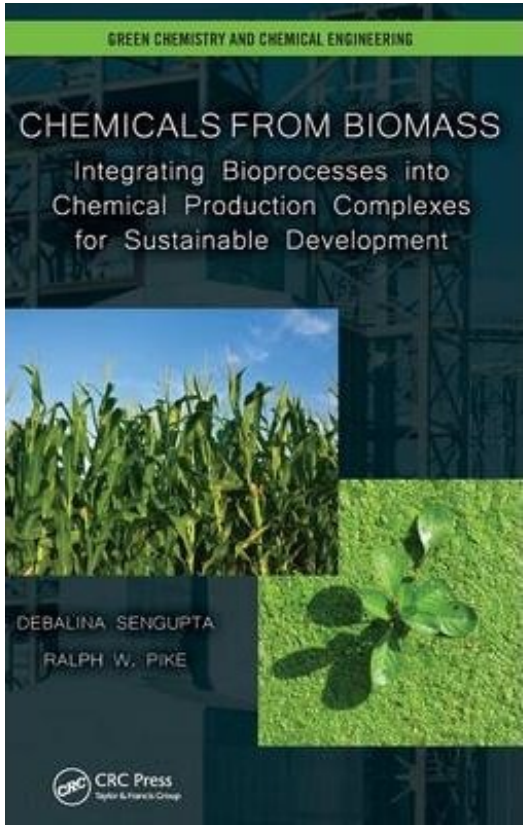
Associate Director at the TEES Gas and Fuels Research Center (2016- Present);
Water Energy Food Nexus Coordinator, Texas A&M Energy Institute (2018-Present);
Graduate Faculty, Artie McFerrin Department of Chemical Engineering, Texas A&M University (2020-Present)

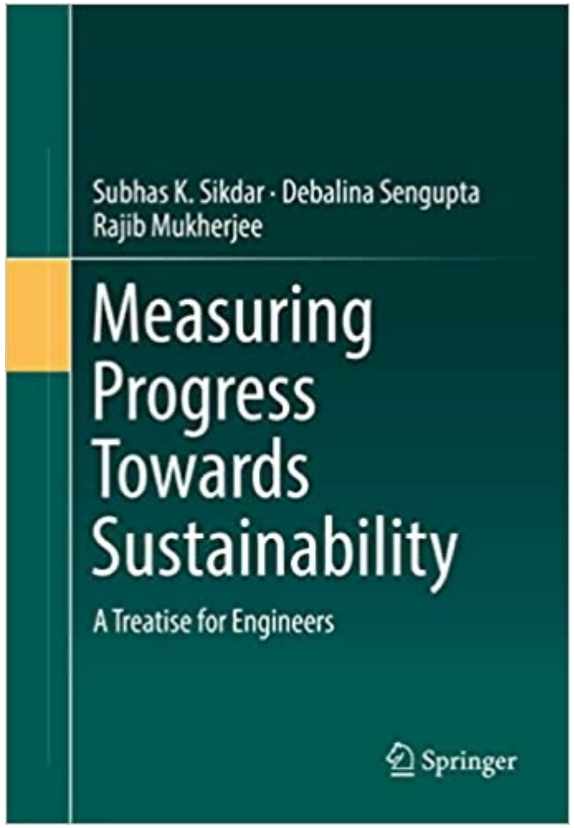
Past Positions:
Lecturer, Artie McFerrin Department of Chemical Engineering, TAMU 2017 – 2019
Post Doctoral Research Associate, Texas A&M University 2014 – 2015
ORISE Post Doctoral Fellow at the National Risk Management Research Laboratory, US Environmental Protection Agency, Cincinnati, OH 2010 – 2014
Doctorate (Chemical Engineering): Louisiana State University 2005 – 2010
Bachelor (Chemical Engineering): Jadavpur University, India 1999 – 2003

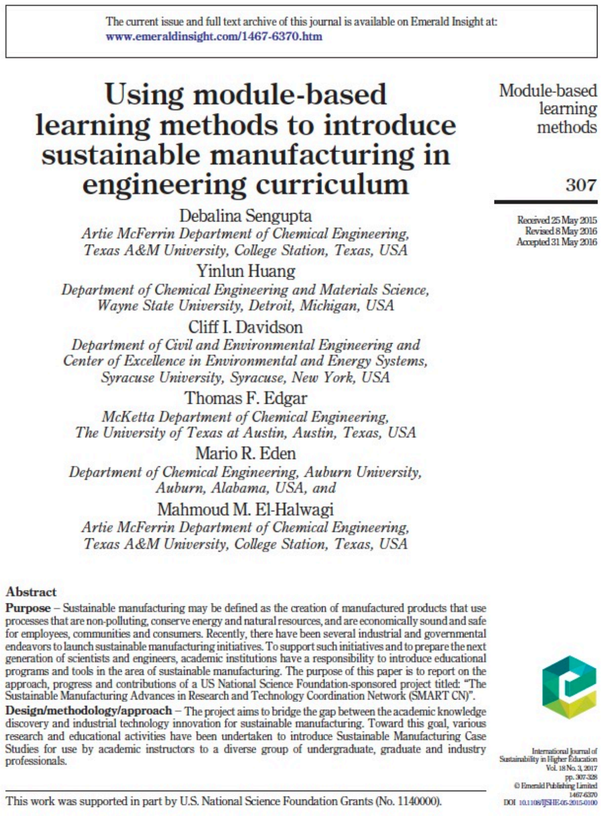
American Institute of Chemical Engineers:
Past Chair, Environmental Division, 2020
Chair, Fuels and Petrochemicals Division, 2021-22
Programming Chair, Environmental Division, AIChE 2015-17
Director, Environmental Division, 2011-14 and Fuels and Petrochemical Division, 2016-19

Editorial Affiliations:
Associate Editor: Sustainable Chemical Process Design, Frontiers in Sustainability;
Review Editor: Computational Methods in Chemical Engineering, Frontiers in Chemical Engineering;
Topic Editor: MDPI Sustainability

Publications of Interest



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Module-based learning methods

307

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Using module-based learning methods to introduce sustainable manufacturing in engineering curriculum

Debalina Sengupta
Artie McFerrin Department of Chemical Engineering, Texas A&M University, College Station, Texas, USA
Yinlun Huang
Department of Chemical Engineering and Materials Science, Wayne State University, Detroit, Michigan, USA
Cliff I. Davidson
Department of Civil and Environmental Engineering and Center of Excellence in Environmental and Energy Systems, Syracuse University, Syracuse, New York, USA
Thomas F. Edgar
McKetta Department of Chemical Engineering, The University of Texas at Austin, Austin, Texas, USA
Mario R. Eden
Department of Chemical Engineering, Auburn University, Auburn, Alabama, USA, and
Mahmoud M. El-Halwagi
Artie McFerrin Department of Chemical Engineering, Texas A&M University, College Station, Texas, USA

Abstract
Purpose – Sustainable manufacturing may be defined as the creation of manufactured products that use processes that are non-polluting, conserve energy and natural resources, and are economically sound and safe for employees, communities and consumers. Recently, there have been several industrial and governmental endeavors to launch sustainable manufacturing initiatives. To support such initiatives and to prepare the next generation of scientists and engineers, academic institutions have a responsibility to introduce educational programs and tools in the area of sustainable manufacturing. The purpose of this paper is to report on the approach, progress and contributions of a US National Science Foundation-sponsored project titled: "The Sustainable Manufacturing Advances in Research and Technology Coordination Network (SMART CN)".
Design/methodology/approach – The project aims to bridge the gap between the academic knowledge discovery and industrial technology innovation for sustainable manufacturing. Toward this goal, various research and educational activities have been undertaken to introduce Sustainable Manufacturing Case Studies for use by academic instructors to a diverse group of undergraduate, graduate and industry professionals.

This work was supported in part by U.S. National Science Foundation Grants (No. 1140000).

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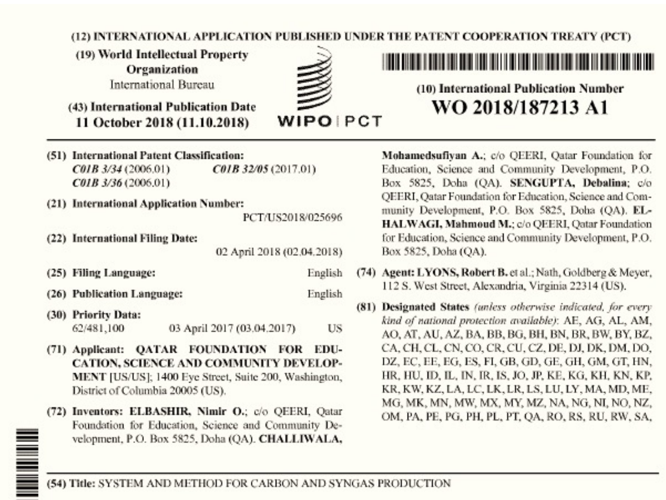
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(71) Applicant: QATAR FOUNDATION FOR EDUCATION, SCIENCE AND COMMUNITY DEVELOPMENT [US/US]; 1400 Eye Street, Suite 200, Washington, District of Columbia 20005 (US).

(72) Inventors: ELBASHIR, Nimir O.; c/o QEERI, Qatar Foundation for Education, Science and Community Development, P.O. Box 5825, Doha (QA). CHALLIWALA, Mohamedsufiyan A.; c/o QEERI, Qatar Foundation for Education, Science and Community Development, P.O. Box 5825, Doha (QA). SENGUPTA, Debalina; c/o QEERI, Qatar Foundation for Education, Science and Community Development, P.O. Box 5825, Doha (QA). EL-HALWAGI, Mahmoud M.; c/o QEERI, Qatar Foundation for Education, Science and Community Development, P.O. Box 5825, Doha (QA).

(74) Agent: LYONS, Robert B. et al.; Nath, Goldberg & Meyer, 112 S. West Street, Alexandria, Virginia 22314 (US).

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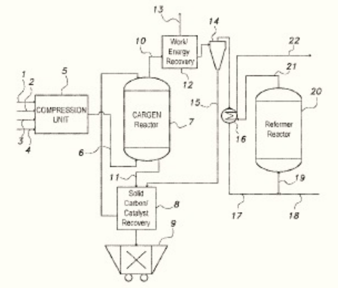


Author of two original books related to quantifying sustainability from engineering context.
Developer of education modules related to sustainable manufacturing for engineering curriculum.
Co-Inventor of the CARGEN process for carbon utilization via dry reforming, improved efficiency of reforming technology achieved with high value MWCNT.
Author or co-author of multiple peer reviewed journal articles and book chapters with over 900 citations.

Before we begin……………..

DIRE-FEWS is a concept, based on advanced systems knowledge, understanding of sustainability and resilience theories, and a compelling need to address disasters faced by many.

…………….. It is work in progress.

It all started with a Big Idea

Growing Convergence Research

NSF 10 Big Ideas

https://www.nsf.gov/news/special_reports/big_ideas/convergent.jsp

CONVERGENCE Research Program: Sustainable Regional Systems Research Network (SRS-RN)

To further develop SRS science, NSF is calling for Full Scale proposals and Planning Grant proposals for Sustainable Regional Systems Research Networks (SRS RN).
The purpose of the SRS RN competition is to develop and support interdisciplinary, multi-organizational teams of investigators and stakeholders.
Teams will work collaboratively to produce cutting-edge convergent research and education that will inform societal actions for future environmental, economic, and social sustainability, addressing grand challenges in sustainable regional systems.

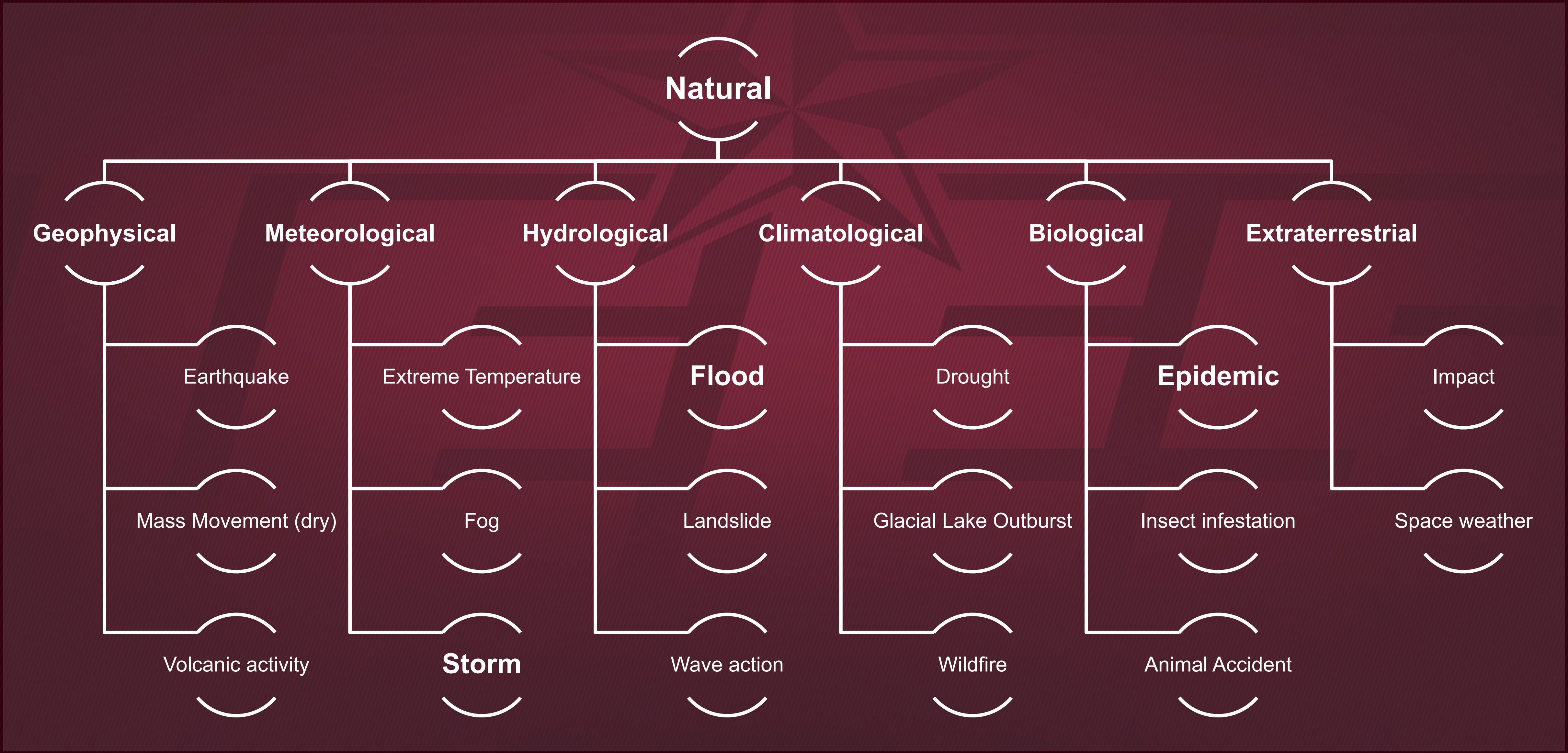
What are Disasters?

An occurrence of a natural catastrophe, technological accident, or human caused event that has resulted in severe property damage, deaths, and/or multiple injuries. As used in this Guide, a "large-scale disaster" is one that exceeds the response capability of the local jurisdiction and requires State, and potentially Federal, involvement. As used in the Stafford Act, a "major disaster" is "any natural catastrophe [...] or, regardless of cause, any fire, flood, or explosion, in any part of the United States, which in the determination of the President causes damage of sufficient severity and magnitude to warrant major disaster assistance under [the] Act to supplement the efforts and available resources or States, local governments, and disaster relief organizations in alleviating the damage, loss, hardship, or suffering caused thereby."

United States Federal Emergency Management Agency (FEMA)

https://www.fema.gov/pdf/plan/glo.pdf

What are Disasters?
Natural



https://www.emdat.be/classification

What are Disasters?
Technological

- Technological disasters are relatively better managed with advanced safety features and control measures.
- Advanced research is required to face challenges at the intersection of Natural and Technological Disasters (natural disaster induced technological failures).
- Human factors in technological disasters is an active area of research.

https://www.emdat.be/classification

Regional Systems and Disasters

A regional system can be geographically comprised of disaster-prone and disaster impacted areas.

The migration of populations from rural to urban systems and vice versa for short- and long-term has been observed as a consequence to natural disasters[1,2,].

1. Berlemann, M. and Steinhardt, M.F., 2017. Climate change, natural disasters, and migration—a survey of the empirical evidence. *CESifo Economic Studies*, *63*(4), pp.353-385.
2. Mbaye, L. Climate change, natural disasters, and migration. *IZA World of Labor 2017*: 346 doi: 10.15185/izawol.346

Relevance to the US Gulf Coast

Filing for federal assistance within one month of Hurricane Katrina included 1.36 million individual applicants (Louisiana (38.6%), Mississippi (28.3%) and Texas (11.6%)) where 46.2% filed from within 100 miles of New Orleans[3], and filings were observed from all 50 states.

Regional Systems in Gulf Coast can be urbanized areas, urban clusters, and/or rural areas for the states of TX, LA, and MS

3. The New York Times, 2005. Katrina's Diaspora, https://archive.nytimes.com/www.nytimes.com/imagepages/2005/10/02/national/nationalspecial/20051002diaspora_graphic.html

SRS-RN Team

Deep integration of Knowledge (DIK)

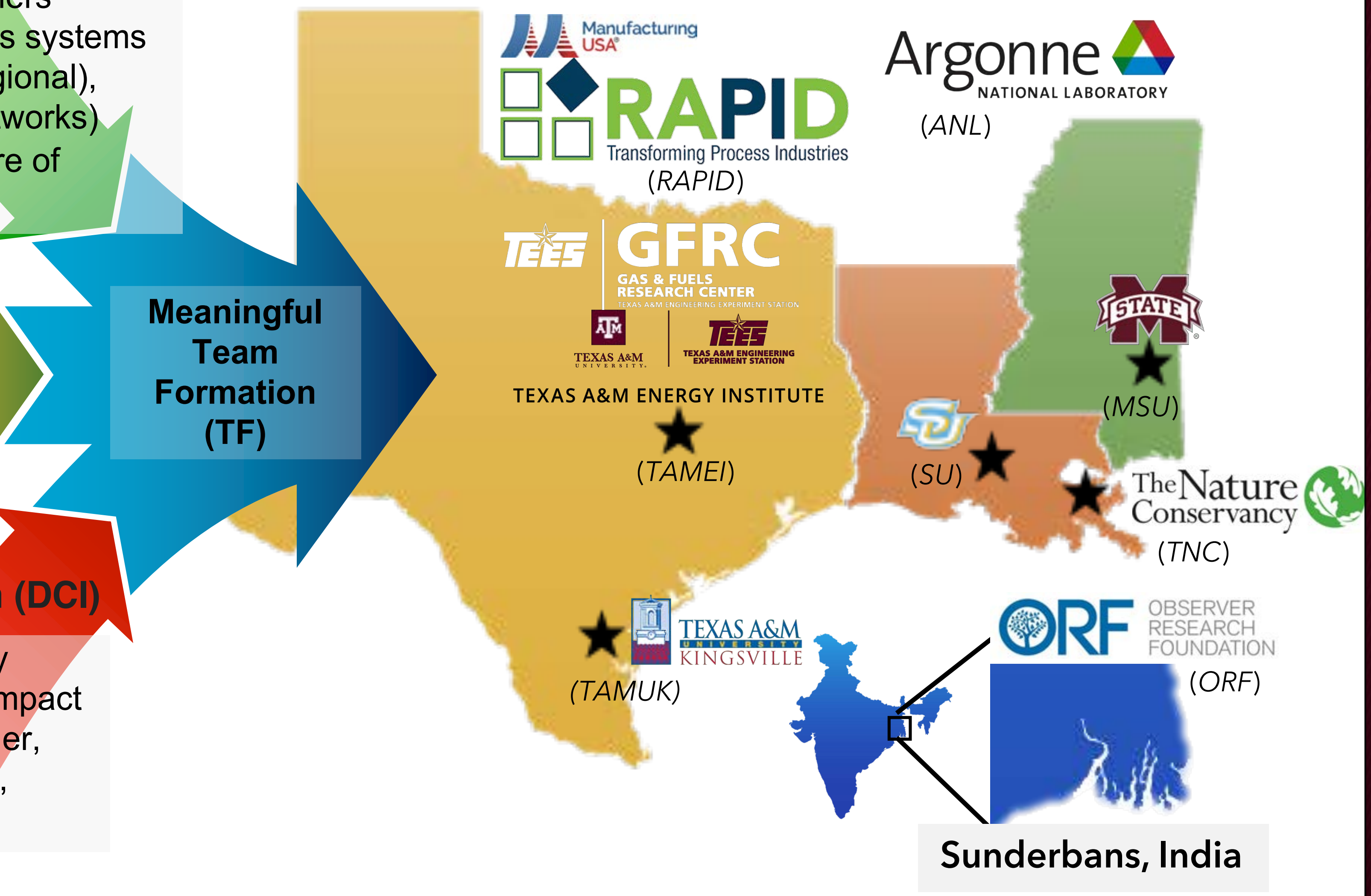
- Combination of fundamental and applied research from academic and non-academic partners
- Multiple scales of technological (process systems and networks), ecological (local and regional), and societal (social capital, informal networks)
  Consideration of resilience as a measure of sustainable regional system

Ecological/Societal Impact (ESI)

- Develop technology considering ESI
- Early stage stakeholder involvement for co-development
- Diversity in stakeholder groups

Diversity and Culture of Inclusion (DCI)

- Develop equitable access to technology
- Involve HSI and HBCU at locations of impact
- Consideration of experience, age, gender, race, ethnicity, religion, skills, language, culture, physical and mental abilities



Components of Regional Systems (stakeholders)

- Communities
- Municipalities
- Local, regional, state, and federal governments
- Social capital organizations
- Educational and research institutions
- Businesses
- Technology providers
- Ecological advocacy groups

Components of Regional Systems (stakeholders)

- Communities
- Municipalities
- Local, regional, state, and federal governments
- Social capital organizations
- ***<u>Educational and research institutions – K-12 STEM</u>***
- Businesses
- Technology providers
- Ecological advocacy groups

Networks of Study

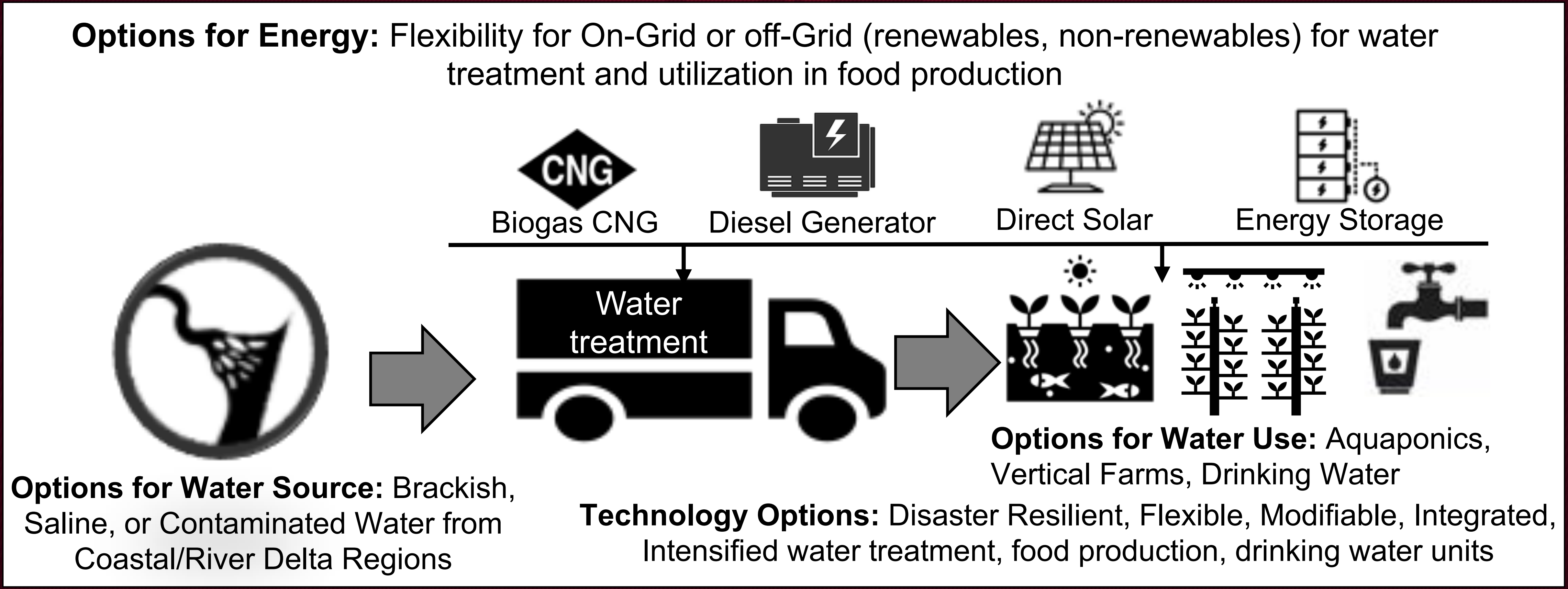
Food, energy, and water networks
Combined FEW system needs
Social networks

Value Proposition

Create a pathway towards studying overall sustainability of regional systems affected by disasters through the development of potentially new class of:

integrated food, energy, and water technological systems

Example:
integrated food, energy, and water technological systems



K-12 Education Needs and Request

- Partnership opportunities for US National Science Foundation project
- Be a part of the Sustainable Regional Systems Research Network (SRS-RN)
- Preliminary content (2-pagers) to develop lesson plan
- Opportunities for participation in RET programs

K-12 Education Learning Objectives

- Incorporate technology for resilience and sustainable development.
- Learn advanced analytical methods and tools to assess and analyze sustainability.
- Apply mathematical fundamentals in conceptual design and optimization for sustainability analysis.

Case Study 1

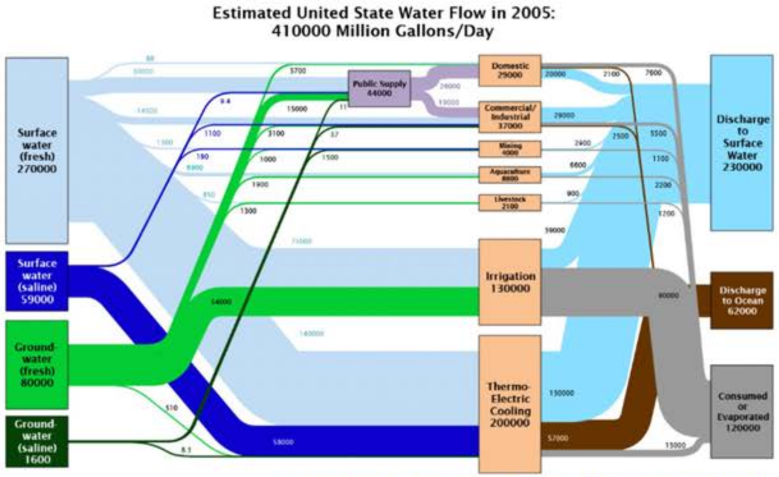
Water System

Check 2-page overview document in the Supplemental Material

Water System

Overview

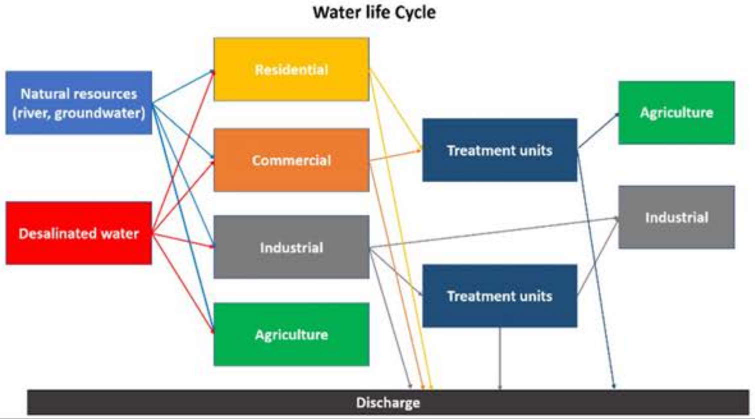
- Water system is needed to meet demands of different sectors like residential, commercial needs, industrial areas, irrigation, and public needs as firefighting.
- Simply, life stops without water as human beings and other creatures significantly depend on water.
- Accordingly, it is important to create a water system that considers collection, treatment, and distribution of water to satisfy all demands.



Water Consumption Flowchart [1]

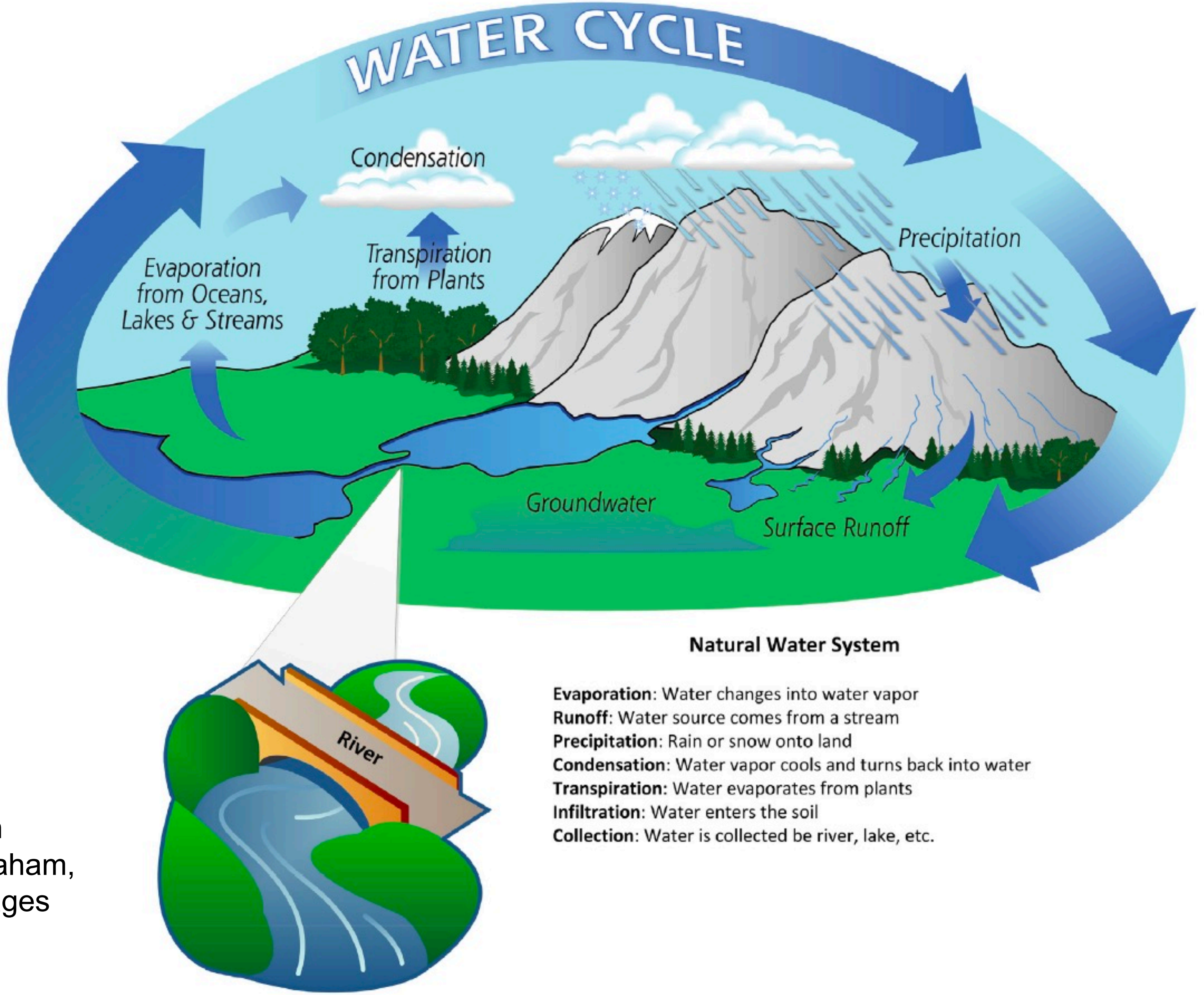
Systems Perspective (A cradle-to-grave water life cycle)

- First, fresh water is made available from two main resources: natural resources and desalinated water.
- The suitable water resource is used based on required flowrate and purity.
- Then, wastewater can be either treated and reutilized or simply discharged.
- Reuse of treated wastewater is controlled by different factors including purity, flowrate, and policies (i.e., treated wastewater from industrial area may not be used for irrigation).



Prepared by Manar Oqbi

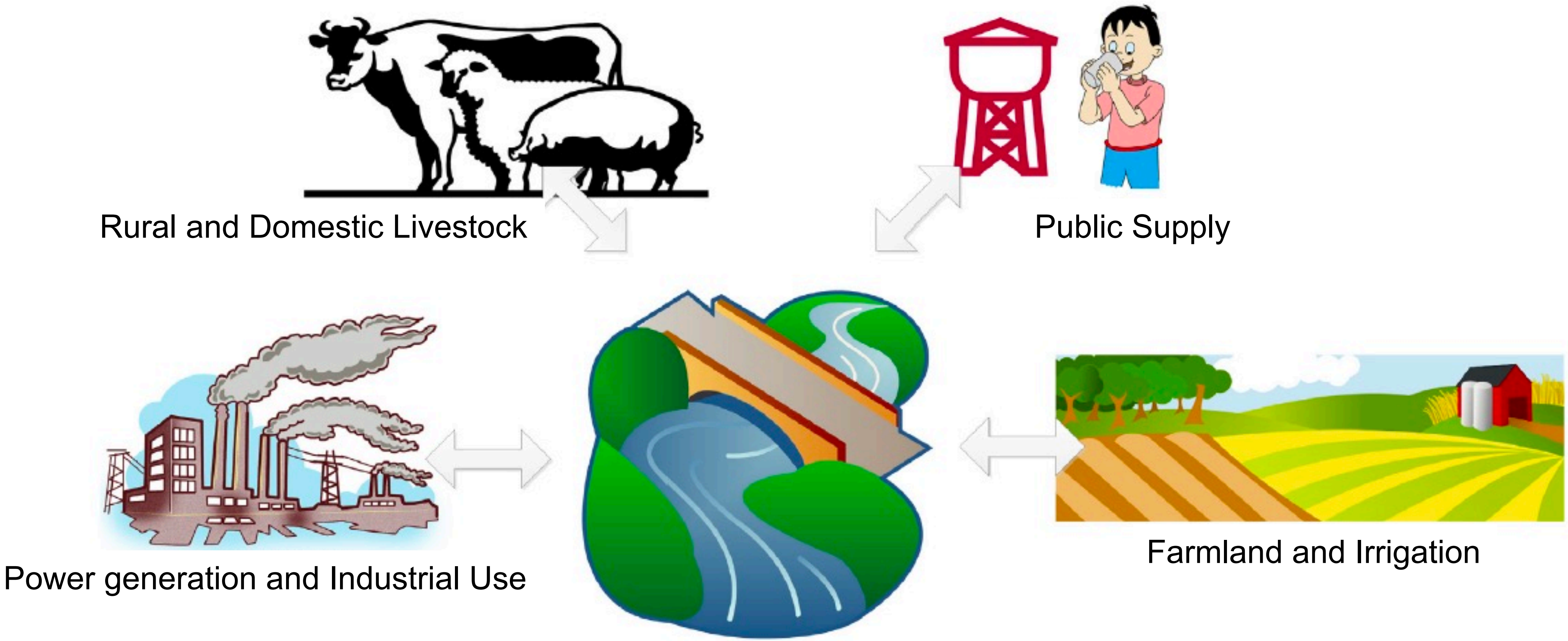
Systems Approach to Water Management



Type I: Global Scale - Water Cycle

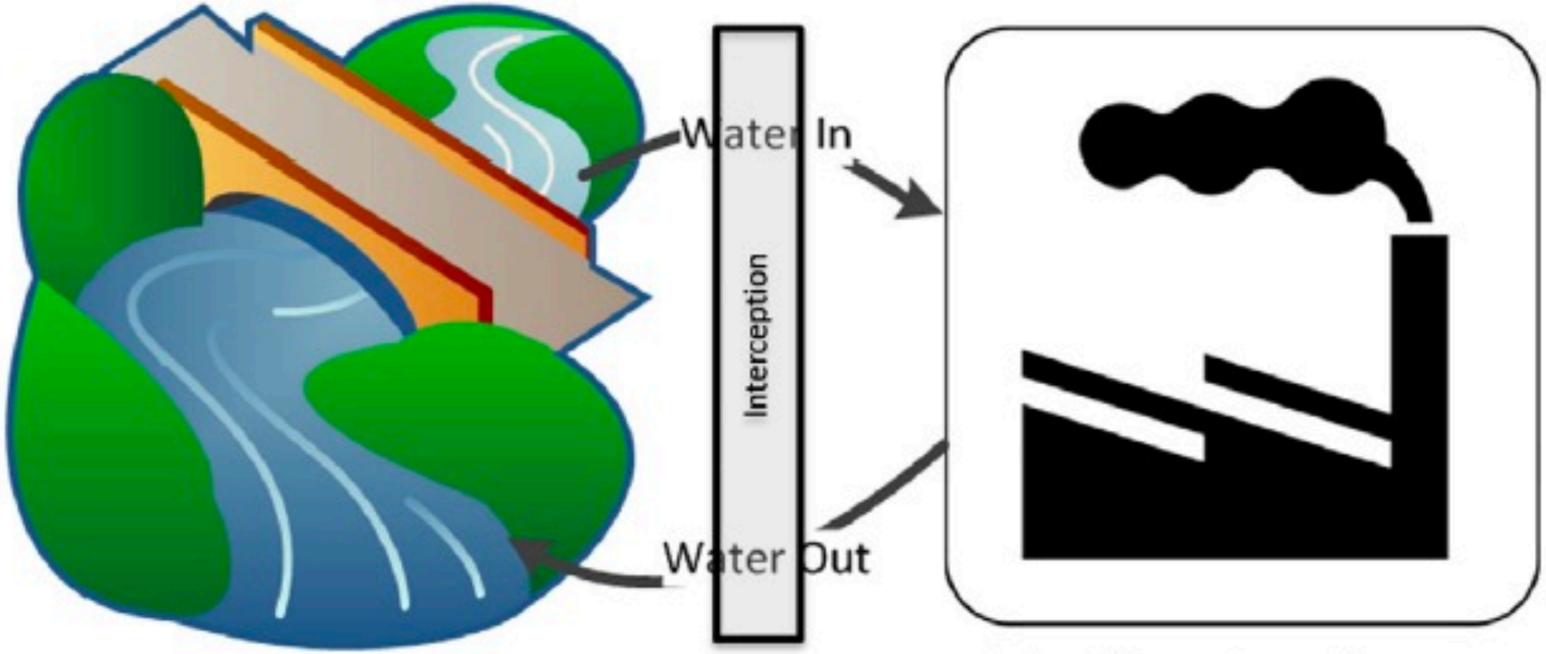
Debalina Sengupta, Mahmoud M El-Halwagi, "Incorporating Systems Thinking in the Engineering Design Curriculum: Path Forward for Sustainability Education", Editor(s): Martin A. Abraham, Encyclopedia of Sustainable Technologies, Elsevier, 2017, Pages 201-213, ISBN 9780128047927

Systems Approach to Water Management



Type II: Systems bounded by geographical boundaries: Managed typically by local authorities and individual entities

Systems Approach to Water Management



Type III: Business Systems: Water Management Network

Interception: Physical and Chemical Processes that prepare the water for use (inlet) from and discharge (outlet) into the natural water systems

Proposed Methodology for Study

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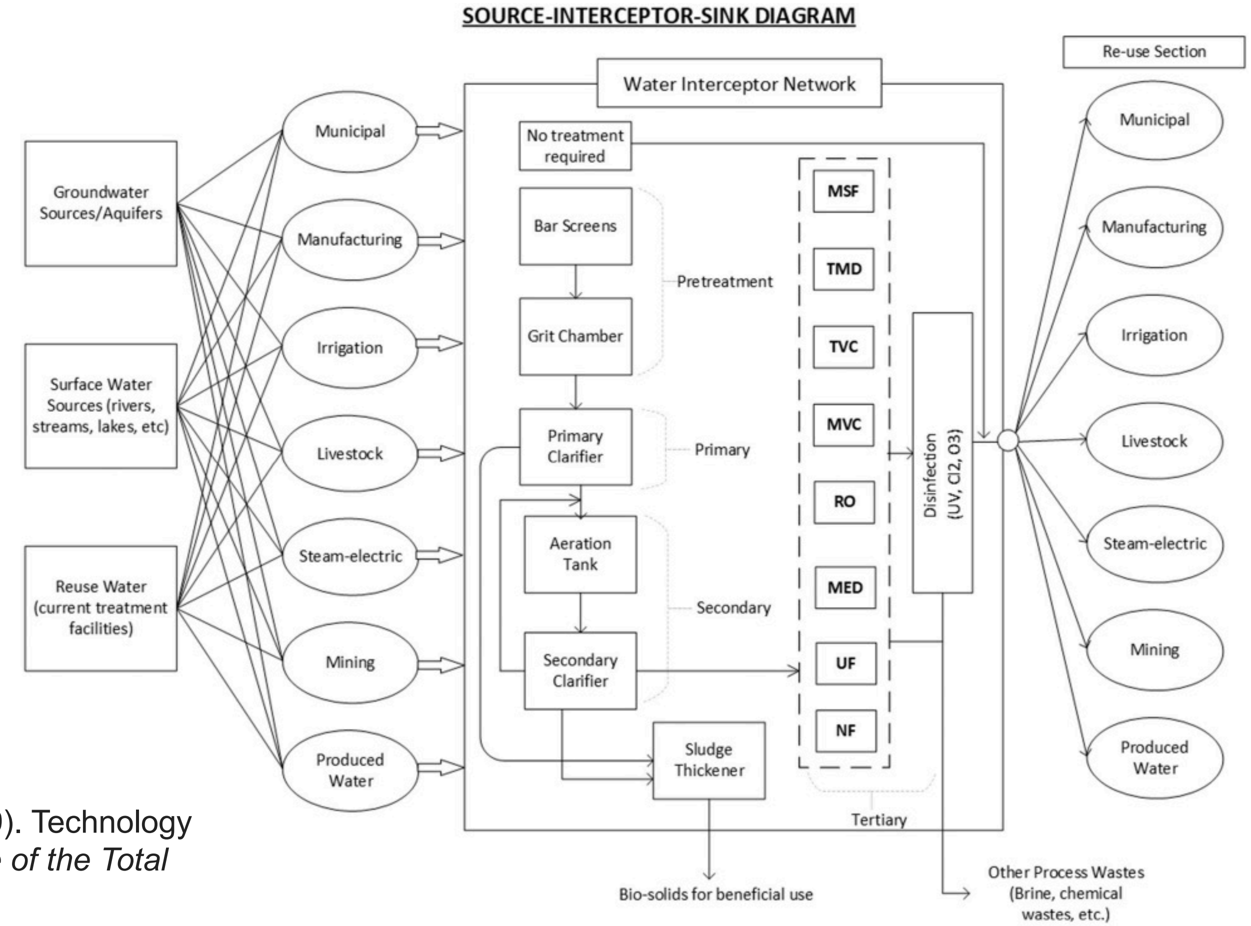
Sustainability Method: Industrial Ecology

Process systems analysis for Energy, Mass, and Property Integration with targets of minimum discharge, cost, and environmental compliance through mathematical modeling techniques and tools.
Potential for economic savings, anchor-tenant approach for industrial ecology.

Mass Integration: Total Quantity of water, inlet and outlet from different industries
Property Integration: Quality of water (inlet), and primarily outlet quality (depends on the type of processes in the processes). E.g. battery waste is different from refinery waste or petrochemicals waste. Necessary for the sustainability of local and regional water quality for health, safety, and economic development
Energy Integration: Energy requirement for the processes supporting water treatment are utilities that require operating costs. Minimization of purchased utilities can be achieved by integrating with excess process energy that is currently wasted



Bhojwani, S., Topolski, K., Mukherjee, R., Sengupta, D., & El-Halwagi, M. M. (2019). Technology review and data analysis for cost assessment of water treatment systems. *Science of the Total Environment*, *651*, 2749-2761

Proposed Methodology for Study

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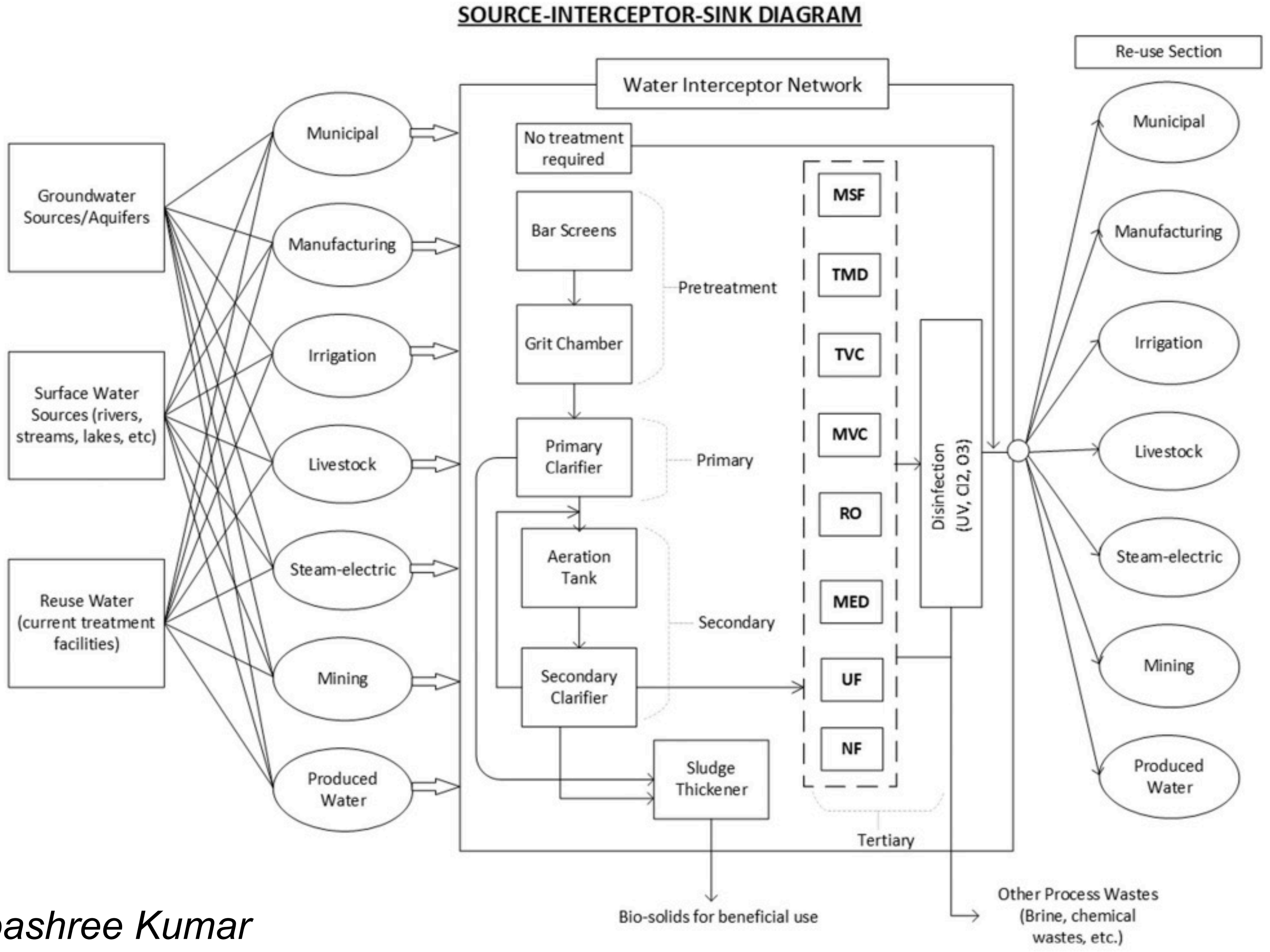
Bhojwani, S., Topolski, K., Mukherjee, R., Sengupta, D., & El-Halwagi, M. M. (2019). Technology review and data analysis for cost assessment of water treatment systems. *Science of the Total Environment*, *651*, 2749-2761



The following section is prepared by Debashree Kumar

Problem statement

- To provide continual water for growing population, desalination is the most preferred option.
- Water treatment costs have reduced due to energy consumption. For instance, seawater desalination costs have reduced from \$0.64 - \$0.80 /m^3 (mid 1990s) for a large sized plant to \$ 0.50 / m^3 for such large RO plants in the current decade.
- This paper provides data from capital cost, operating cost, capacity constraints due to the treatment method capabilities and requirements of the user. The focus of this article is technical and economic outlook to the reader for optimal process selection.
- It also considers macroscopic water network systems (urban + rural)

Water network flowchart

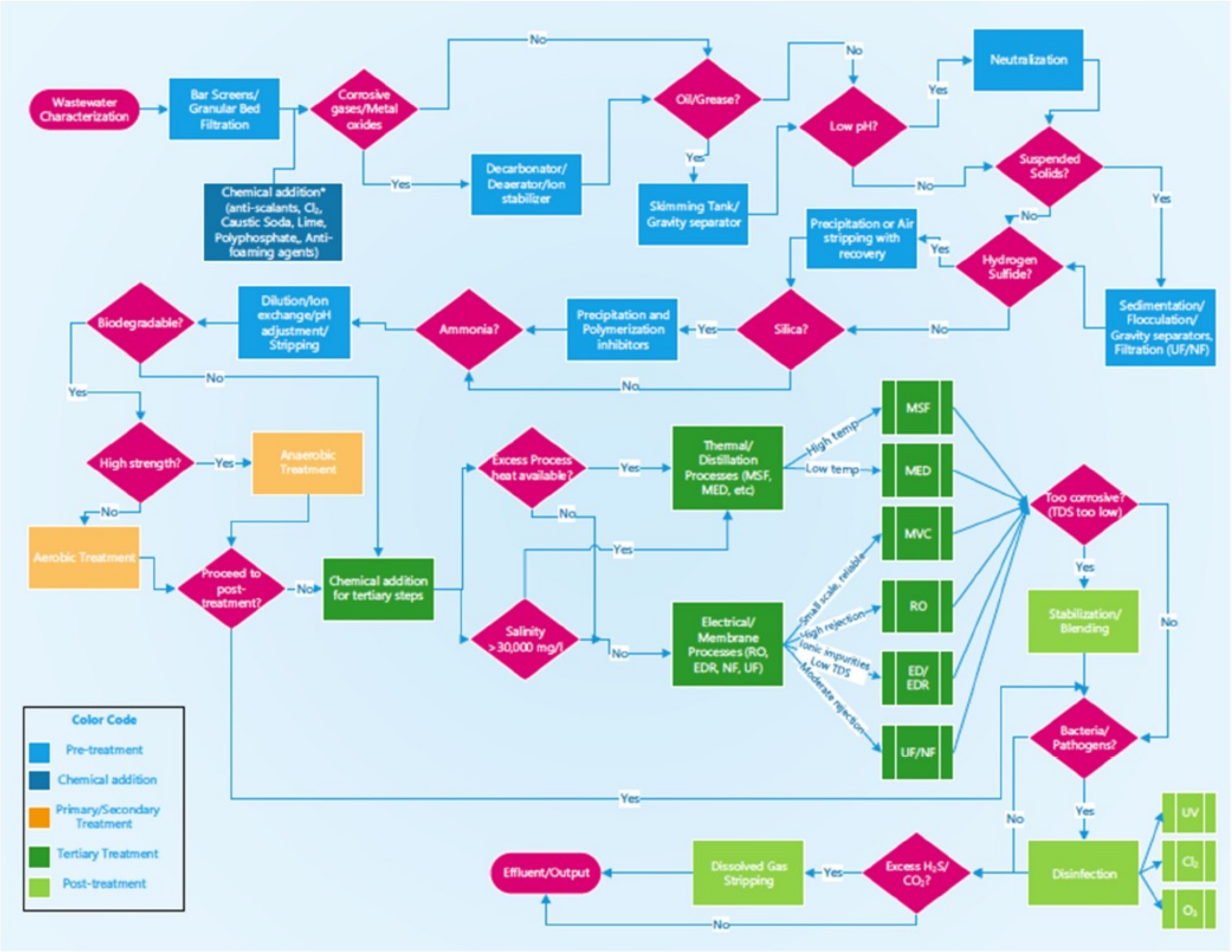


Fig. 1. Flowchart for the screening and selection of water treatment processes.

Method

- The diagram is divided into five parts: water sources, water users, wastewater characterization, intercept or network design (treatment facility), and re-distribution to users.
- Each of these sections is discussed in detail in this article for providing the reader the perspective of the existing water networks.
- The water treatment can be divided into 4 parts: pre-treatment, primary and secondary, tertiary, post- treatment.

Approach

- The cost calculations for these processes was based on two cost considerations:
  - **Capital costs & Operating costs**

- **Capital costs:** Capital expense (CAPEX) include land, equipment, installation, etc. up to the commissioning of the facility. Direct capital costs include the investment for desalination equipment, piping, valves, water intake structure, site preparation, concentrate discharge systems, auxiliary equipment such as water storage, emergency response systems, engineering etc. Indirect capital costs include freight and insurance (~5%), contractor's overhead (~15% of the dollar size of the project), legal, fiscal and administrative fees. Construction and equipment costs constitute the majority of the costs for both thermal and membrane desalination systems.
- **Operating costs:** Operational expenses (OPEX) (also known as operating costs) include labor, energy costs (thermal and electrical), chemicals, insurance, maintenance and spare parts (or membrane) replacement and some indirect costs. These costs are proportional to the quantity of water treated. Indirect costs also referred to as manufacturing overhead and may include repairs and maintenance, electricity for the production facility and equipment, salaries and wages for indirect manufacturing personnel. For thermal processes, energy represents the major cost component (66%) with labor (9%), indirect costs (10%), maintenance (7%) and chemicals (4%) representing the other major cost heads. For membrane processes, the energy demand is lower (41%) than the thermal processes with labor (13%), chemicals (11%), indirect costs (8%) and membrane replacement (5%) making up the majority of the operating costs.

Results

- The goal of this article is to provide an optimal sustainable system for the water treatment network. The two steps involved are process selection and process integration.
- Process Selection Parameters:
  - Feed water quality (salinity, hardness, pH, BOD, etc.)
  - Capacity (quantity)
  - Desired product quality
  - Energy availability
  - Site location
  - Environmental considerations

Results

- Integration/ Coupling Strategies
  - Cogeneration
- Hybrid systems
  - Use of renewable energy
- Emerging technologies
  - Membrane based technologies
- Thermal based technologies
  - Other alternative technologies

Conclusion

- The selection of a certain treatment pathway depends on a variety of factors such as energy availability, site-specific constraints, feed water quality and quantity, desired product specifications, economics and environmental regulations.
- The unit product cost was lowest for brackish water RO (\$0.3–0.7/ m3) followed by seawater RO (\$0.7–1.4/m3).
- There has been a shift towards RO in the past 10–15 years due to its multiple economic and environmental advantages over thermal methods.
- Hybrid systems offer numerous advantages over conventional methods due to the increased flexibility and reduction in cost.

Case Study 2

Energy System

Check 2-page overview document in the Supplemental Material

Hydrogen (Energy systems)

Overview

Hydrogen is the most abundant element in the universe. It exists in various compound and constitutes about 75% of the matter. It is used for variety of applications in industry for upgrading chemicals. It is seen as the next generation fuel as we move towards decarbonization and is a clean energy source. The biggest advantage it offers is the highest calorific value (141.7 MJ/kg) when it undergoes combustion.

Systems Perspective

Hydrogen is mainly produced industrially by Steam methane reforming process (~95%) which is among the most energy intensive processes. This process also emits greenhouse gases thus exacerbating the carbon footprint(120gCO2/MJ) of the process. It is also produced by electrolysis of water by employing renewable energy sources thus having almost zero carbon footprint. There is ongoing research to capture the carbon dioxide from SMR process reducing the carbon footprint of SMR Process and also employing carbon dioxide as the feed for producing hydrogen, moving towards negative carbon footprint.

Sustainability

One of the biggest sustainability challenges entail the decarbonization of the production routes. Greenhouse gases increase the temperature of the air and also can displace the air we are breathing. It also has safety related issues as hydrogen's density (0.089 kg/m3) is very low and hence causes frequent leakages in pipelines and when released in open atmosphere in its elemental state can cause violent exothermic reaction and it is highly flammable.

Disaster Disruptions

Disasters like violent thunderstorms can catalyze the combustion of hydrogen at low energy levels causing explosions. Also, during power outages in hydrogenation reactions which are exothermic reactions can shoot up the temperature of reactions if not controlled.

Resilience

Building a modular network of hydrogen like transporting hydrogen tankers during disasters when manufacturing set up is facing an issue by pipelines can help in being disaster resilient. Also having cogeneration systems when power outages take place help in reviving the electricity of the unit. Having a redundant unit in case one unit undergoes an issue can help recuperate the loss because of one plant. Hydrogen production routes can be switched between renewable energy sources (Electrolysis of water) and non-renewable energy sources (SMR) when there is shortage of either.

Prepared by Ankush Rout

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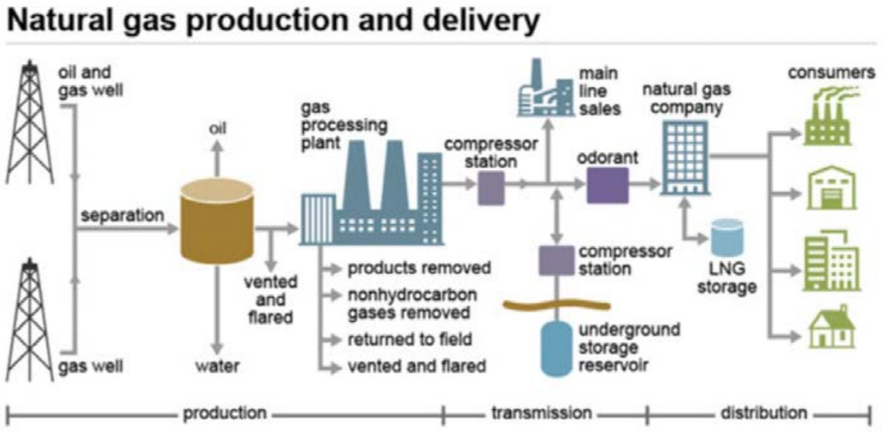
Check 2-page overview document in the Supplemental Material

Energy System: Natural gas for electricity generation (upstream process)

US is the leading producer of natural gas. Natural gas provides cleaner, affordable, abundant, environmentally friendly fuel. The improved extraction technologies and reduced emissions has led this fuel to become the leading technologies to power an electricity grid. The energy from natural gas fuel is released as heat which propels turbines and boils the steam which runs the generator. The distribution pipeline failure (leakage or rupture) of the gas is the major problem in the reliability of this infrastructure. The largest consumer of energy is as utilities for various manufacturing and property units.



https://www.energy.gov/fecm/natural-gas-technologies-rd

Systems Perspective

The following steps are involved in the production of natural gas for electricity production:

Extraction: Horizontal drilling and sophisticated pressure techniques are used to release natural gas from shale. The new innovative technologies of "hydraulic fracturing" and "horizontal drilling" has created what is commonly known as the "Shale Revolution". Secondly, capturing the natural gas via pipeline system. Cleaning the natural gas: To increase the calorific efficiency of the gas, the gas should be "clean." (free from impurities). Storage and distribution: Natural gas is stored in large storage tanks before being used. Distribution, transportation, and transmission of natural gas is via gas pipeline system.

Prepared by Debashree Kumar

Transition Energy: Natural Gas

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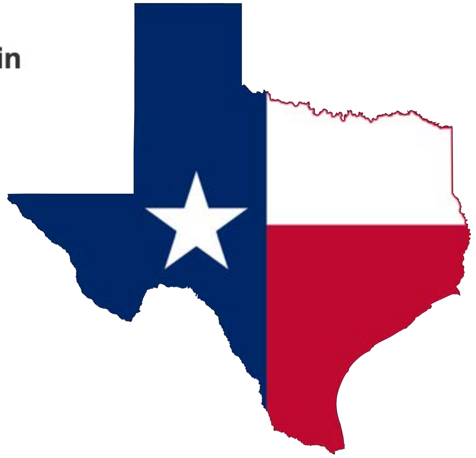
Natural Gas

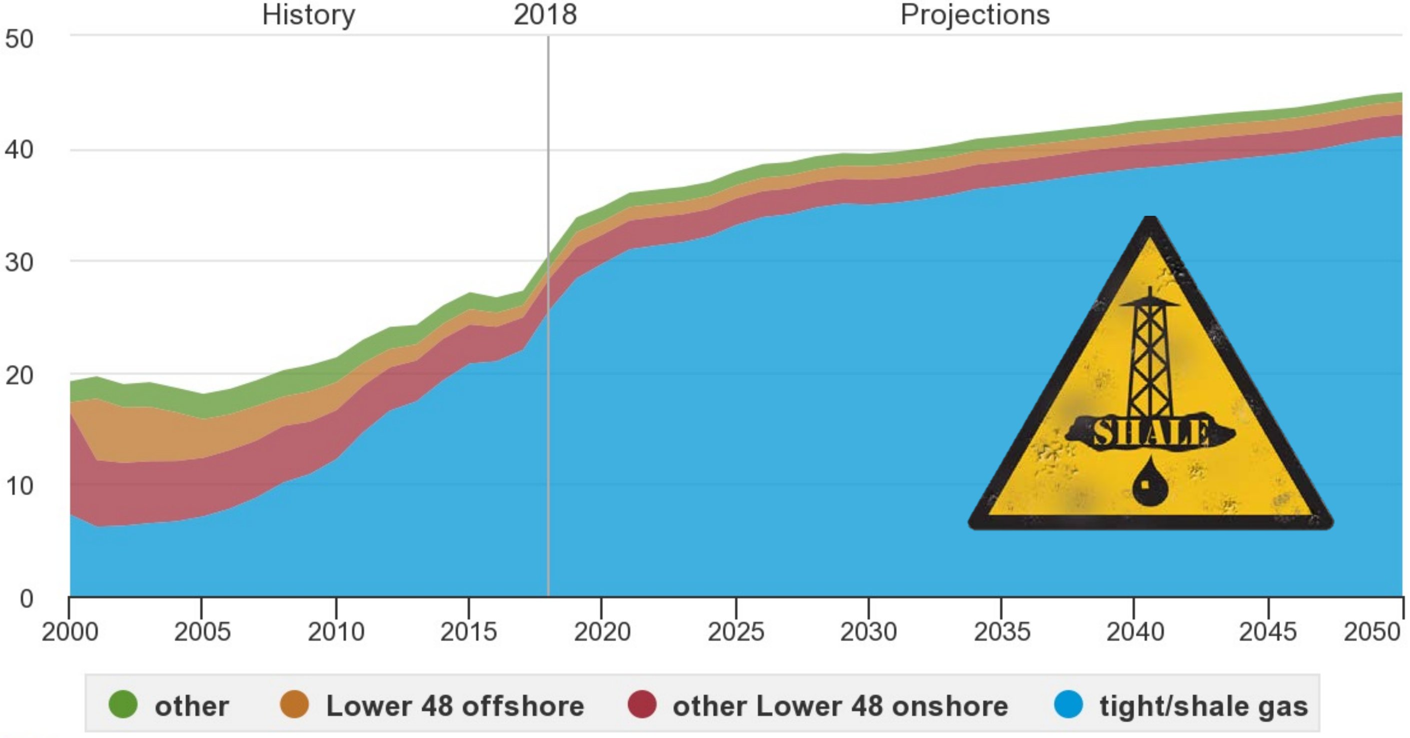
The top five natural gas-producing states and their share of total U.S. natural gas production in 2019

23.9%	20.0%	9.3%	8.5%	7.7%
Texas	Pennsylvania	Louisiana	Oklahoma	Ohio



U.S. dry natural gas production by type, 2000-2050

trillion cubic feet



eia Source: U.S. Energy Information Administration, *Annual Energy Outlook 2020 Reference case*, January 2020

- ❑ Natural gas is clean burning hydrocarbon compared to coal or crude oil
- ❑ Since 2006-07, US has seen increase in production of shale oil and gas
- ❑ TX and PA have been at the center of this activity
- ❑ Provides domestic energy and plays key role in energy security and independence
- ❑ Several ecological, economic, and societal issues have been reported that hinder sustainable development of this resource

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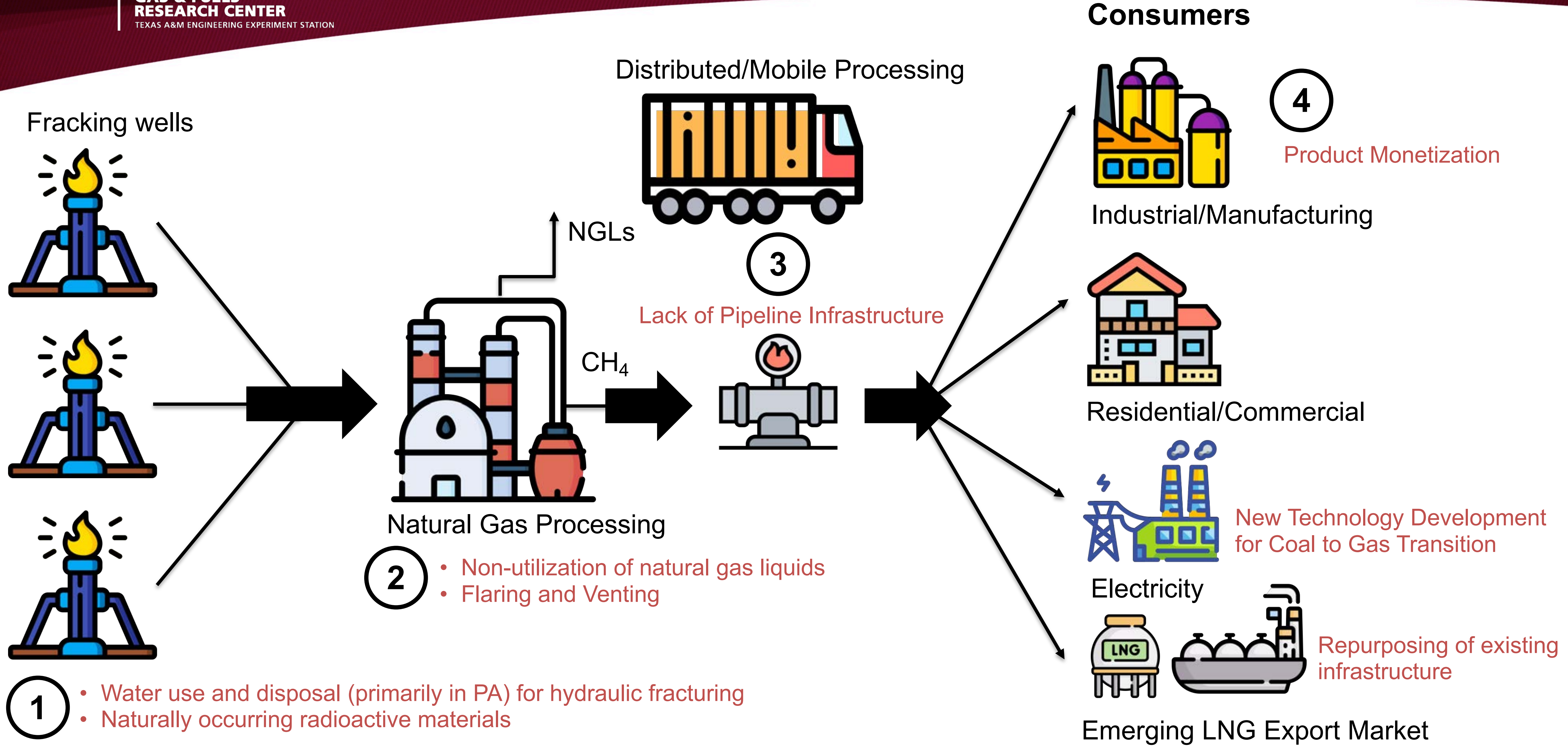
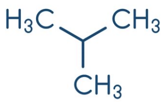
Shale Gas Supply Chain



Sustainability Challenges in Shale Play Development

2 3 4 Gas Monetization

	ethane	propane	butane	isobutane	pentane
Formula	H_3C-CH_3				
Application Area	Ethylene for plastics, petrochemical feedstock	Residential and commercial heating, cooking fuel, petrochemical feedstock	Petrochemical feedstock, blending with propane or gasoline	Refinery feedstock, petrochemical feedstock	Natural gasoline, blowing agent for polystyrene foam
Final Products	Plastic bags, plastics, antifreeze	Home heating, small stoves and barbeques, LPG	Synthetic rubber for tires, LPG, lighter fuel	Alkylate for gasoline, aerosols, refrigerant	Gasoline, polystyrene, solvent

Example: On purpose Propylene Expansion projects on the US Gulf Coast

- Depending on shale plays, the gas has higher quantities of natural gas liquids (higher hydrocarbons, C2, C3, C4, C5, C5+ ….) compared to conventional wells.
- Historically, NGLs have provided advantage to the petrochemicals market in the United States.
- Oil and natural gas producers are increasingly targeting liquids-rich parts of supply basins.
- Higher crude oil prices influence the value of NGLs; low prices of crude have deterred their utilization.
- (Lack of) Supply chain infrastructure (pipelines) has promoted intensification and distributed manufacturing.

PSE Methods and Tools Used: *Optimization, Sensitivity Analysis, Process Intensification, Pinch Analysis, Mass and Energy Integration.*

Related Publications: Bohac, E., Sengupta, D. and El-Halwagi, M.M., **Design and Techno-Economic Analysis of Separation Units to Handle Feedstock Variability in Shale Gas Treatment**. In *Process Intensification and Integration for Sustainable Design* (eds D.C. Foo and M.M. El-Halwagi). https://doi.org/10.1002/9783527818730.ch2, 2021.
Agarwal, A., Sengupta, D., and El-Halwagi, M.M., 2018. **A Sustainable Process Design Approach for On-Purpose Propylene Production and Intensification.** *ACS Sustainable Chem. Eng.,* 6(2), p. 2407-2421 **[FEATURED on the cover for June 2018]**
Al-Douri, A., Sengupta, D. and El-Halwagi, M.M., **"A Multicriteria Optimization Approach to the Synthesis of Shale Gas Monetization Supply Chains"** in "Natural Gas Processing from Midstream to Downstream", edited by Nimir O. Elbashir, Mahmoud M. El-Halwagi, Ioannis G. Economou, Kenneth R. Hall, Pages 219-234, 2018.
Al-Douri, A., Sengupta, D., and El-Halwagi, M., 2017. **Shale gas monetization–A review of downstream processing to chemicals and fuels.** *J Nat Gas Sci. Eng.,* 45, p. 436-455.

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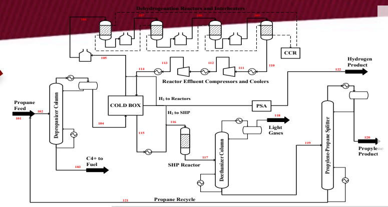
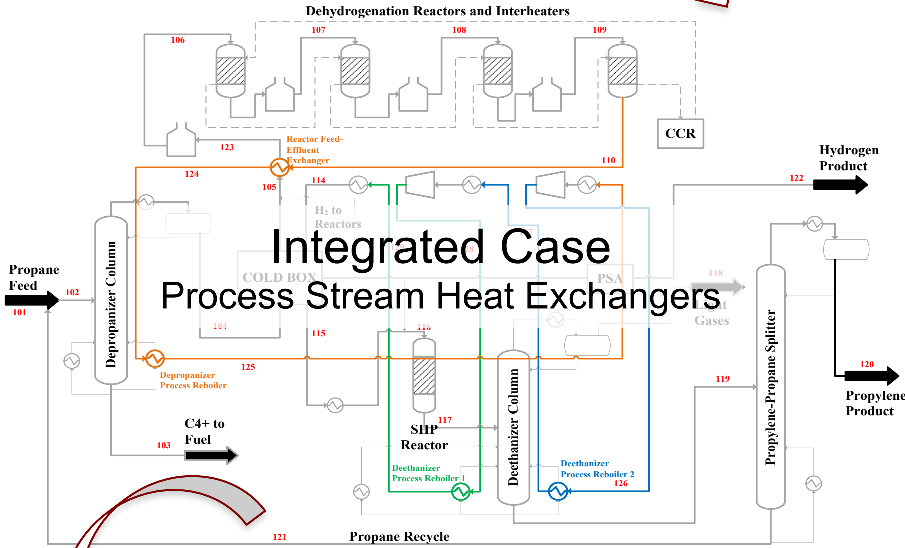
4 On-purpose Propylene Production



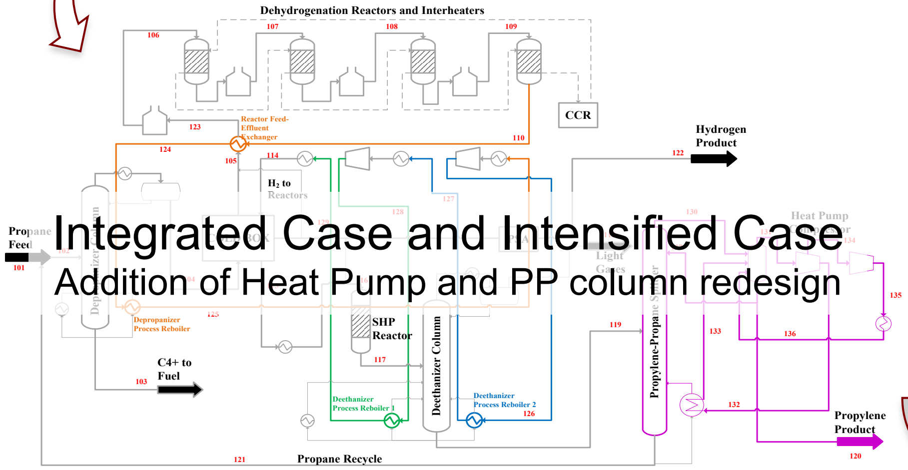
Base Case

Completely unintegrated design (no major information, other than stoichiometry)



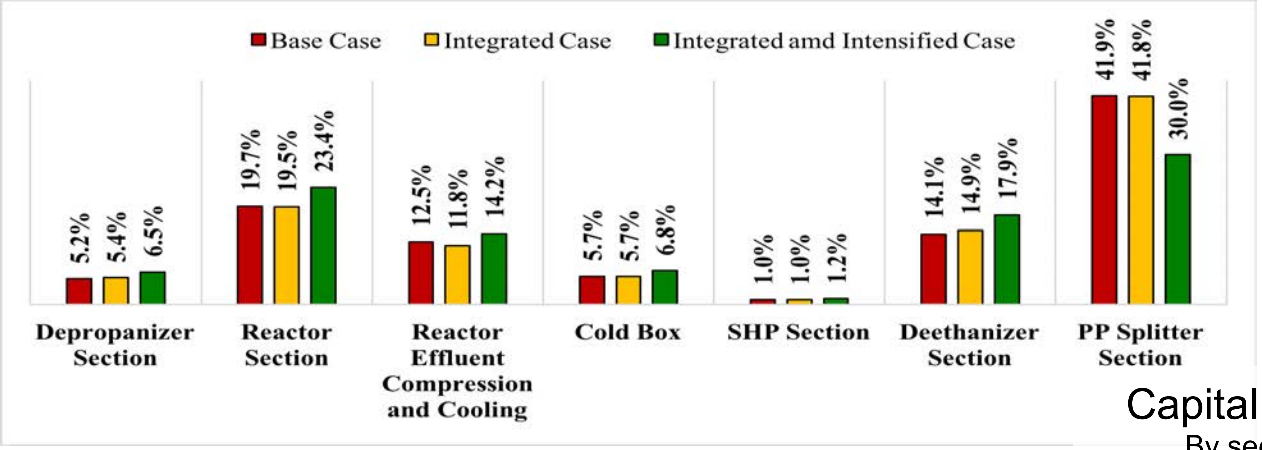
Integrated Case

Process Stream Heat Exchangers



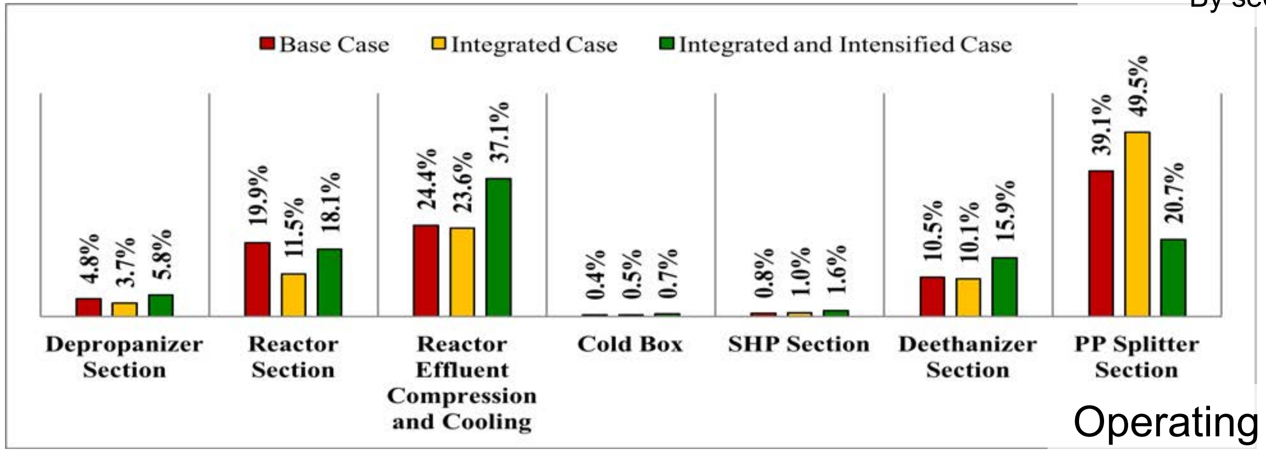
Integrated Case and Intensified Case

Addition of Heat Pump and PP column redesign



Capital Costs

By section



Operating Costs

By section

Integrated Case and Intensified Case + WHR + OGR

Waste heat recovery from fired heaters
Off gas recovery as fuel

Agarwal, A., Sengupta, D., and El-Halwagi, M.M., 2018. **A Sustainable Process Design Approach for On-Purpose Propylene Production and Intensification.** *ACS Sustainable Chem. Eng.*, 6(2), p. 2407-2421 **[FEATURED on the cover for June 2018]**

Case Study 3

Food System

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Check 2-page overview document in the Supplemental Material

Saline Water Intrusion on U.S. Gulf Coastal Agricultural Food Production

Prepared by Dr. Leisha Vance

The IPCC 2021 Summary for Lawmakers Report states that mean sea level has risen approximately 202mm since 1901, with average yearly increases of 1.3mm from 1901-1971, 1.9mm/yr from 1971 to 2006, and 3.7mm/yr from 2006 to 2008. Unfortunately, the report attributes these increases to human influence. The report also finds extreme weather events such as droughts, heatwaves and tropical cyclones have increased in frequency and intensity over the past four decades. [1]

Additionally, hurricanes are lasting 50% longer on the first day of landfall than they did in 1950; this phenomenon correlates with rising sea surface temperatures[2]. The combination of sea level rise and hurricanes has provided increased opportunities for stormwater surges and short-term flooding in coastal areas, and subsequently, more opportunities for saline water intrusion in U.S. Gulf coastal lands.

Continuous exposure to saline water can create or worsen saline soil conditions. Some amount of saline is in all soils, but if soil electroconductivity (EC) levels are over 4 dS/m, they are classified as saline soils. Plants receive nutrition through root system water uptake in the form of soluble salts, however when high soil saline levels are too high at plant root zones, plant growth in inhibited and agricultural production losses occur.

Besides sea level rise, storm surges and heavy hurricane precipitation, other factors cause saline water intrusion. Droughts and dry climate increase evaporation rates, which can pull soil salts to the soil surface. Poor farming practices can also increase salinity in soils. Irrigating with saline water or if the soils are already saline, not irrigating enough to leach salt from the soils keeps the salinity levels high in the root zones. Removal of deep-rooted vegetation allows salty water tables to rise closer to the surface and crop plant root zones. Over-irrigation also leads to water pooling, which can then amplify evaporation rates and pull saline water into upper soil profiles. Overapplication of fertilizers enhances the nitrification process which also accelerates soil salinization.

How Saline Soils Affect Crops

Water naturally moves from lower salt concentration area into areas of higher salt concentration; if the soil around the plant root zones is higher in salts, water moves away from plant roots into the more salty environment. With less water available in root zones, plants become dehydrated and wilt, just as they would in a drought situation. No additional amount of irrigation will improve this state. Excessive soluble salts also inhibit plant uptake of other necessary nutrients like calcium, potassium, etc., and nutritional

Prepared by Dr. Leisha Vance

Let us get out of this. Together.

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