Beneficial Electrification Industrial Heat

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Electrification of Industrial Processes

- US DOE Industrial Decarbonization Roadmap provides clear insight into the impact of broad economic sectors on energy utilization and green house gas emissions.[1]
  - Significant components of industrial energy inputs can be decarbonized through electrification technological solutions.
  - Process heat represents an outsized component of industrial energy usage
  - Numerous large-scale industries in the Carolinas rely upon natural gas fired heat generation for manufacturing processes.
    - Pulp and paper
    - Food and beverage
    - Chemical production
  - Electrification of process heat represents a near term technology application that can dramatically reduce CO_2 emissions.
  - Positive environmental impact of industrial electrification relies upon clean electrical energy sources at economically competitive cost.

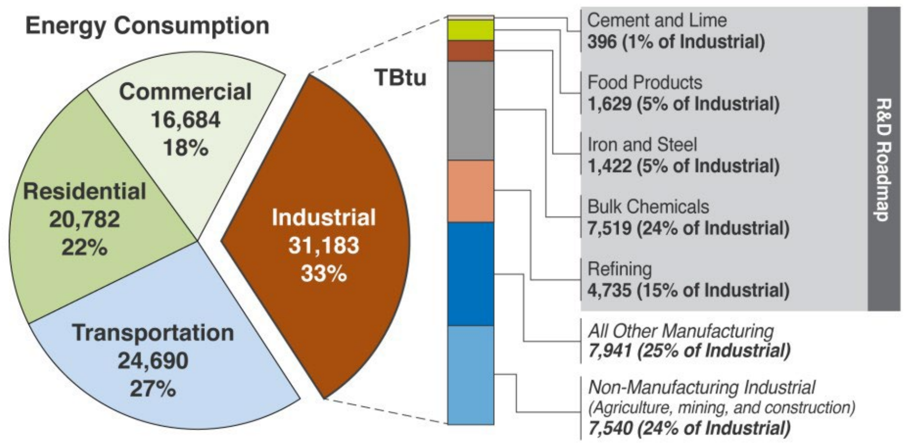
1. "Industrial Decarbonization Roadmap", United States Department of Energy, Publication DOE/EE-2635, September 2022

Energy Consumption

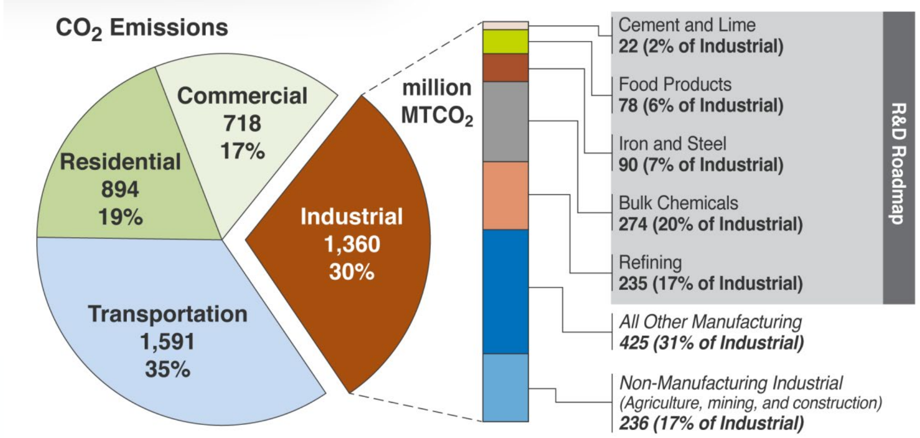
The industrial sector of the US economy accounts for 1/3 of all US energy consumption

- Subsectors within DOE R&D Roadmap account for 15.7 Quadrillion Btu (4600 TW-H)
- Over 50% of all manufacturing energy is used by two subsectors.
  - Chemical processing
  - Food and Beverage

The industrial sector of the US economy is responsible for 30% all CO_2 emissions.



US Energy Consumption by Economic Sector 2020.[3]



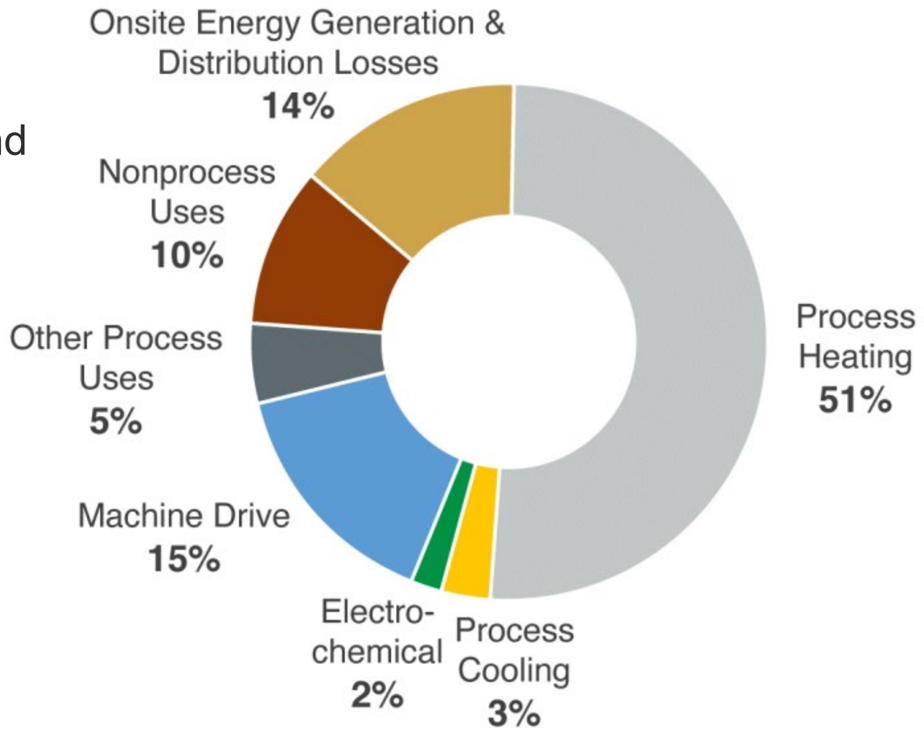
US CO_2 Emissions by Economic Sector 2020.[3]

3. "Annual Energy Outlook 2021 with Projections to 2050," U.S. Energy Information Administration, February 3, 2021, https://www.eia.gov/outlooks/archive/aeo21/. See Table 19. Energy-Related Carbon Dioxide Emissions by End Use.

Process Heating

The magnitude of process heat energy use and its carbon footprint makes process heat a major opportunity for low-carbon solutions.

- Over 50% of all manufacturing energy is used for process heating.[4]
  - In 2018, a total of 7,576 trillion Btu of fuel, steam, and electric energy were consumed for process heating.
  - less than 5% of these operations are electrified.
- Process heating accounted for 360 million metric tons of CO_2e GHG emissions
  - 31% of the manufacturing sector's total energy-related emissions.[4]



3. "Manufacturing Energy and Carbon Footprint: All Manufacturing (2018 MECS)," U.S. Department of Energy Advanced Manufacturing Office, December 2021, https://www.energy.gov/sites/default/files/2022- 01/2018_mecs_all_manufacturing_energy_carbon_footprint.pdf.

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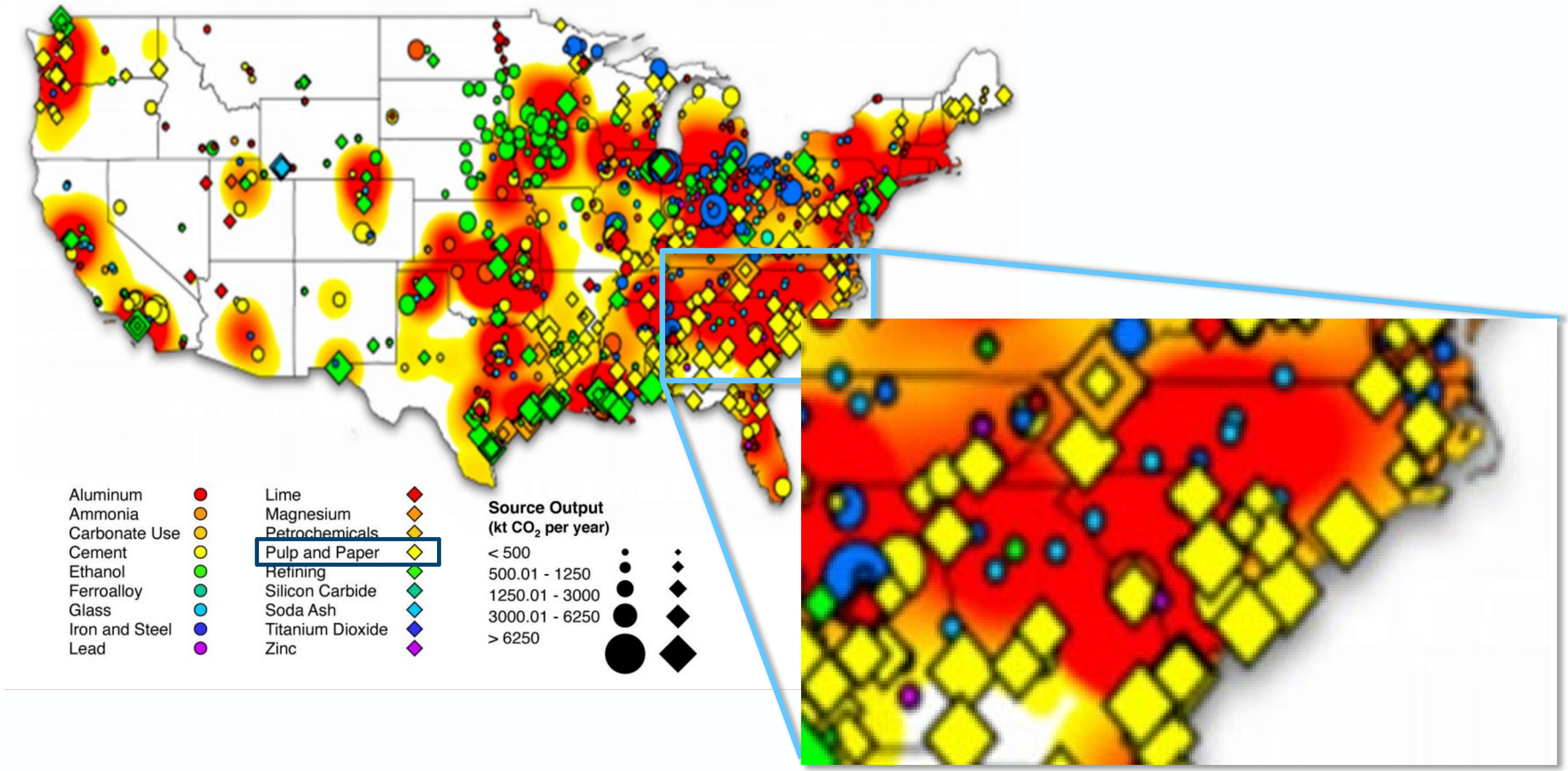
Impact on the Carolinas



Distribution of CO_2 Output by Industrial Subsectors – 2017 [4]

4. Peter C. Psarras et al., "Carbon Capture and Utilization in the Industrial Sector," Environmental Science and Technology 51, no. 19 (2017): 11440–4.

Public-Private Partnerships in R&D

Successful applied research and development partnerships between industry and academia have defining features.

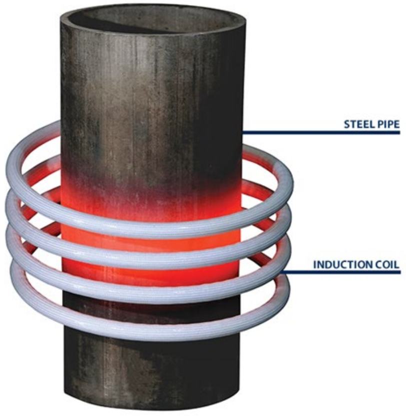
1. Targeted return on investment
   - Well defined business case
   - Alignment with funding agency goals

   } Techno-economic justification
2. Technical expertise in depth
3. Well defined deliverables
4. Well defined division of labor
5. Established relationships

Public-Private Partnerships in R&D

Decarbonization of Process Steam through Electrification of Heating

- US DOE Office of Efficiency and Renewable Energy (EERE)
    - Industrial Efficiency and Decarbonization
        - FOA 0002840
    - Topic Area 5: Decarbonization of Paper and Forest Products
    - Inductively Coupled Electrified Steam Generator
        - 5 MW pilot demonstrator
        - Scalable to 1 GW
        - Single case study installation in 2021 accounted:
            - 247 GW-hrs of natural gas steam production in 2021
            - > 1,000,000 metric tons CO_2
    - Siemens Energy, Inc. – Prime Award Recipient
        - Bob Warren, Siemens Energy – Principle Investigator
        - Jim Gafford, UNC Charlotte
        - Dr. Jay Kapat, University of Central Florida



SIEMENS energy

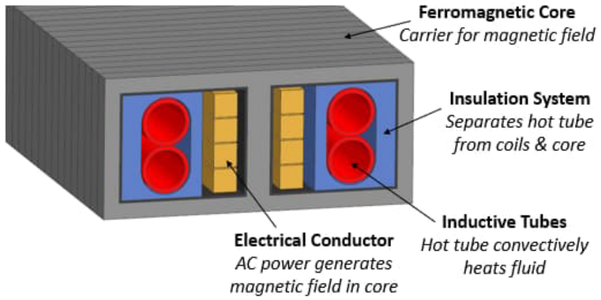
UNIVERSITY OF NORTH CAROLINA CHARLOTTE
Energy Production and Infrastructure Center

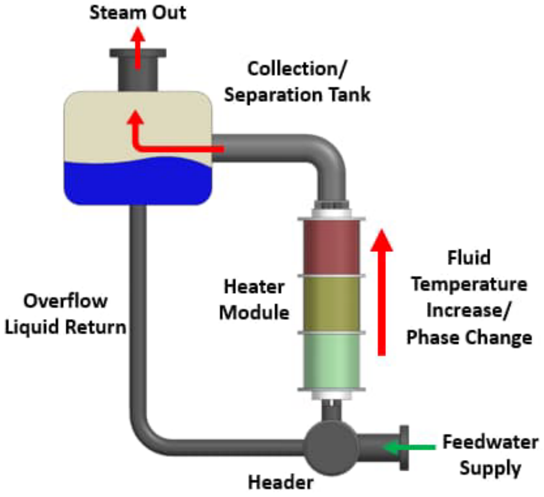
UCF

Public-Private Partnerships in R&D

Decarbonization of Process Steam through Electrification of Heating

- Tier 2 Project: TRL 6 to 7
  - Pilot scale technology in a relevant environment
  - Phase 1: R&D
    - Heater Conceptual Development – Siemens Energy
    - System Thermal Modeling – UCF
    - Power and Control System Development – UNC Charlotte
  - Phase 2: Design and Test
    - Heater Prototype Fabrication – Siemens Energy
    - Power and Control System Design – UNC Charlotte
  - Phase 3: Installation and Demonstration
    - Installation with industry partner at an operational facility





Beneficial Electrification Assumes Decarbonized Generation

High Voltage DC Transmission - How to Land Offshore Wind

- HVDC Voltage Source Converters are being deployed to connect offshore wind production to the onshore grid.
- Valve halls using incumbent technology are problematic in scale.
- Incumbent IGBT technology is gaining traction in adoption.
- Significant technology advancements will be made to de-risk these systems this decade.

A Hitachi Energy HVDC VSC hall[5]

5. P. Fairley, "High-Voltage DC Power Roars Ashore in Europe: Scotland's next-generation transmission network foreshadows a global grid transformation," in IEEE Spectrum, vol. 61, no. 01, pp. 28-31, January 2024

Public-Private Partnerships in R&D

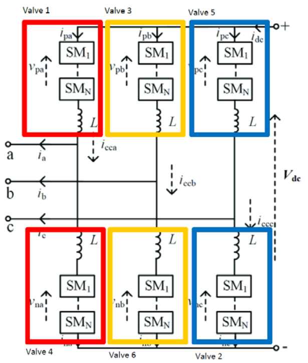
Low Cost ,High-Performance, Reliable, Modular, and Scalable Power Electronic Valves for HVDC Converters

- US DOE Office of Efficiency and Renewable Energy (EERE)
  - Innovative DEsigns for high-performAnce Low-cost HVDC Converters (IDEAL HVDC)
    - FOA 0003141
  - Topic Area: HVDC Voltage Source Converters
  - Scalable Supercascode SiC JFET Modules and Cells for HVDC Converter Optimization
    - Pareto Analysis of Optimal 320 kVDC Converter Leg
    - 20 kVDC Supercascode SiC JFET Module
    - 40 kVDC NPC Converter Cell
  - UNC Charlotte – Prime Proposing Agency
    - Dr. Madhav Manjrekar, UNC Charlotte – Principle Investigator
    - Dr. Pete Losee, Qorvo
    - Dr. Andrew Lemmon, University of Alabama
    - Brandon Meier, TNEI

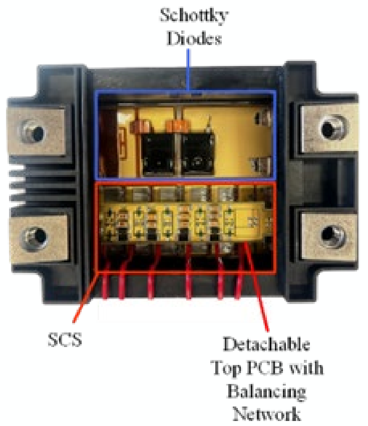
Public-Private Partnerships in R&D

Low Cost ,High-Performance, Reliable, Modular, and Scalable Power Electronic Valves for HVDC Converters

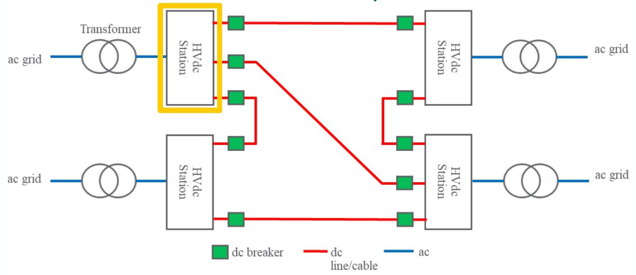
- Develop and demonstrate scalable HVDC converter modules
  - Task 1: System Optimization Study
    - Identify system parameters
    - Develop cost function
    - Identify pareto-optimal designs
  - Task 2 & 3: Design and Fabrication
    - Supercascode module design
    - MMC cell design
    - Proof of concept hardware prototype
  - Task 4: Characterization and Evaluation
    - Module performance characterization
    - Converter cell demonstration
  - Task 5: Techno-Economic Impact
    - System cost/performance impact
    - BOP considerations
    - Site impact



System Optimization



Hardware Design and Fab



System Impact