Exploring community co-benefits, barriers, and future research gaps for industrial decarbonization in the United States

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Abstract and Executive Summary

Decarbonizing industry in the United States consists of a series of compelling and difficult technical, social, economic, political, and cultural challenges. This Working Paper focuses on two core social elements of industrial decarbonization: community co-benefits, and emerging barriers, risks, and challenges. Based on a review of the academic literature, it asks: What are the possible benefits of industrial decarbonization for local communities? What are the most significant barriers and risks? Lastly, what is the status of research within both areas, what topics are already explored significantly and which methods are primarily utilized, and which topics are underexamined and which methods underutilized? It ends by offering recommendations for future research to address six apparent gaps within the evidence base. These are: (1) developing new conceptual frameworks specific to industrial decarbonization, (2) broadening the consideration of co-benefits, (3) undertaking new data collection via surveys, (4) harness new forms of evidence especially qualitative evidence, (5) consider further portfolio approaches and crosscutting issues, and (6) appreciate the stakeholder networks and regional governance dynamics of industrial decarbonization.

1. Introduction

Decarbonizing industry in the United States represents a complex, daunting technical challenge. The industrial sector is elemental to the productivity of the economy in the United States, providing critical products such as electronics, machinery, metals, chemicals, and textiles. However, the extraction and manufacturing of these items contributes to about one-third of energy related carbon dioxide emissions across the country.[1] Reaching net-zero emissions will require the United States to mitigate more than 6 billion tons of annual economy-wide emissions by 2050, with annual mitigation of 1.5 billion tons expected. The U.S. Department of Energy describes the industrial sector as technically "difficult to decarbonize" because of the diversity of fuels and services it harnesses across very heterogenous operations clustered across different types of factories and processes.[2] This framing as a technical challenge lends itself to technical solutions such as advancing early-stage research and development in carbon capture and utilization and hydrogen technologies, improving the energy-efficiency of industrial processing, scaling new prototypes through demonstrations, electrification of heating, and investing in new sources of low-carbon electricity supply (among others).[3]

However, this convenient and even compelling framing obscures many of the nontechnical aspects of the industrial decarbonation challenge, aspects that involve social and even ethical considerations. Communities and workers may see their homes and livelihoods tied to oil and gas production and fossil-fuel consuming industries severely disrupted. Whether and how these industries decide to comply with government climate policies and public pressures to phase-out fossil fuels has the potential to transform the cultural, economic, and political landscape. The paths such players choose could position the United States as a market leader in cleaner, lower-carbon emitting value chains and help drive change beyond American borders. Equally possible are scenarios whereby fossil-fuel producing and consuming industries continue business-as-usual, or worse, leave the United States to do so in "pollution havens" abroad, where they may increase their negative impacts in less-regulated jurisdictions while leaving communities behind in a wake of further deindustrialization.

This Working Paper focuses on two core social elements of industrial decarbonization: community co-benefits, and emerging barriers, risks, and challenges. It ends by offering recommendations for future research to address six apparent gaps within the evidence base.

2. Research questions and approach

The three central questions guiding this paper are: What are the possible benefits of industrial decarbonization for local communities? What are the most significant barriers and risks? Lastly, what is the status of research within both areas, what topics are already explored significantly and which methods are primarily utilized, and which topics are underexamined and which methods underutilized?

The methodology for the working paper is document analysis via a literature review.[4] This process involves reading a corpus of published materials to offer an investigation of recent literature covering a range of subjects at various levels of completeness and comprehensiveness. More specifically, the literature review targeted peer-reviewed academic journals published in English, over the past 20 years, using keywords in their titles and abstracts such as "industrial decarbonization" and "community benefits," "co-benefits," "co-impacts," "barriers," "challenges," "risks" and "social acceptance." The aim was to provide an illustrative, but by no means exhaustive or representative, overview of the relevant literature on the social and community dynamics of net-zero industry with a focus on the United Strates.

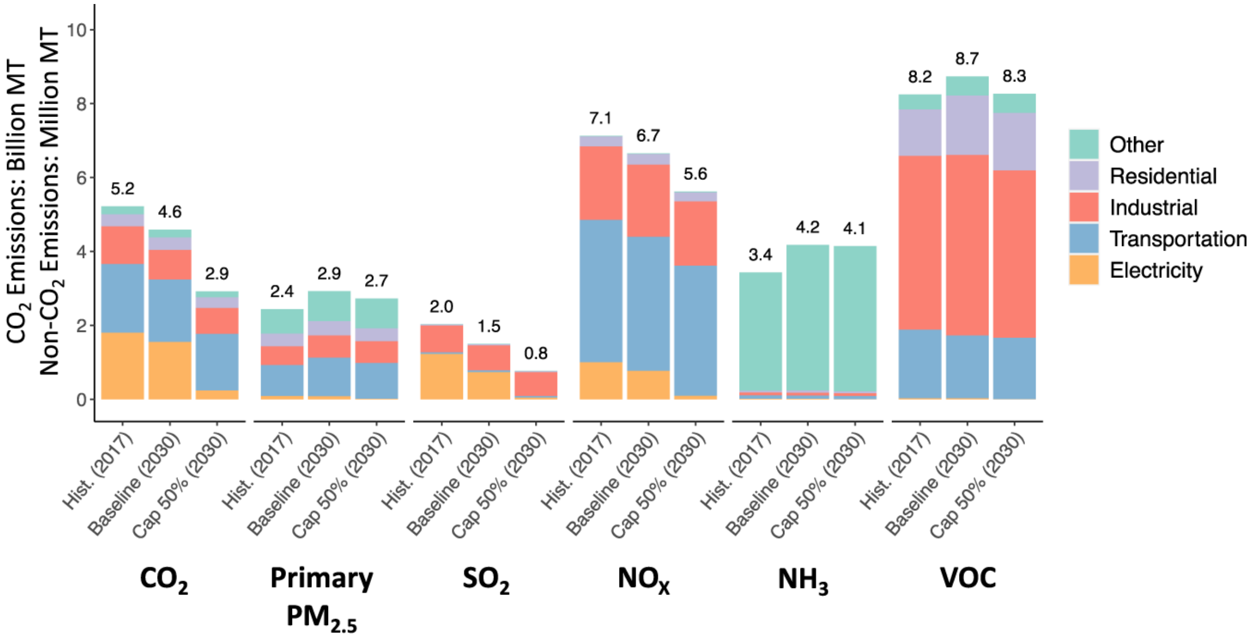
3. Charting community co-benefits of industrial decarbonization

Industrial decarbonization can provide a range of benefits to local communities, ranging from jobs and job security to investment and community growth and even innovation spillovers. It can also enable improved energy security and/or lower energy services costs or result in reduced air pollution and other environmental benefits.

Maintaining or even growing the American manufacturing sector was seen as a critical benefit, as it can provide communities with jobs but also indirect economic benefits such as tax revenue, innovation spillovers, and enhanced resilience. Approximately 12.2 million manufacturing jobs exist in the United States, and as many as 107,000 to 131,000 new high-wage jobs could be created through the necessary capital investment needed for decarbonization by 2035.[5]

Improved air quality and health gains are another considerable benefit. Picciano and colleagues examined the air quality benefits from industrial decarbonization and noted multiple scenarios where it would significantly reduce all forms of pollution, including particulate matter, volatile organic compounds, sulfur dioxide and nitrogen oxides (see Figure 1).[6] Wang and colleagues calculated that even in relatively greener economies such as California, decarbonization would provide about 14,000 fewer premature deaths by 2050 and that 35% of these would come from disadvantaged communities, enhancing equity. [7] That same study projected that the monetary value of those health improvements would reach about $215 billion, far surpassing the estimated cost of $106 billion. In simpler terms: when health co-benefits are included in the assessment, industrial decarbonization more than pays for itself.

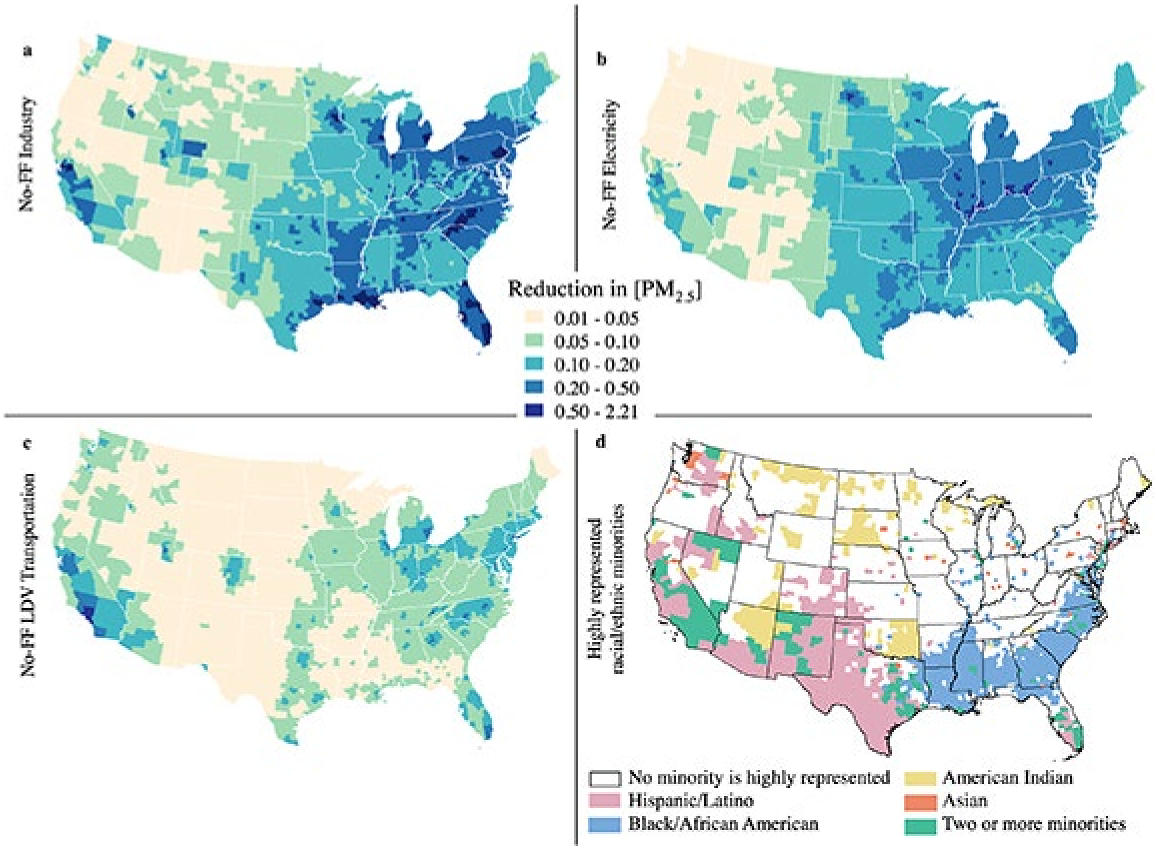
Figure 1: The air quality benefits of industrial decarbonization in the United States (compared to other sectors of decarbonization such as transport or homes)



Source: [8] Note: Industrial emissions reductions are in red and appear for every pollutant category with the most significant reductions in volatile organic compounds.

Gallagher and colleagues examined decarbonization pathways from health and environmental justice lens and reached similarly positive conclusions.[9] As shown in Figure 2, they estimated that industrial decarbonization (or "fossil-fuel industry," a proxy for it) would reduce the risk of primary particulate matter emissions by up to 21% and that they would do so by curbing multiple sources, not just direct sources from factories but indirect sources from burning, agriculture, and fugitive dust from unpaved roads. Nitrogen and sulfur dioxide emissions would be reduced by roughly 10%. Regional patterns of improved air quality are also notable, with industrial decarbonization producing the most significant air pollution benefits in in the Southeast, along the Great Lakes, as well as in Pennsylvania, California, and New York. They estimated that industrial decarbonization would yield $90.5 billion in annual public health benefits, more than the electricity scenario (only $66.1 billion in benefits) and more than the transport scenario ($43.3 billion). In terms of racial equity, the study estimated that the groups most benefitting from reduced exposure to air pollution were communities of color in the South (where 58% of the African American population resides) along with urban areas in the North; Hispanic populations in California, Arizona, New Mexico, and Texas would benefit the most; Asians in California, Washington, and Texas would benefit the most. . Conversely, the opposite holds true as well: failing to decarbonize industry would largely and disproportionately harm communities of color or communities suffering high poverty rates.[10]

Figure 2: Changes in ambient particulate matter pollution for industrial decarbonization (panel a) compared to electricity (panel b) and transport (panel c), with racial diversity patterns shown in panel d.



Source: [11] Note: Highly represented denotes that a racial/ethnic minority group's population is greater than the national share (Hispanic 18.7%, Black 12.1%, Asian 6.1%, and Native 5%.

ACEEE modeled national CO2 and PM2.5 emission profiles as well as facility upgrades aimed at decarbonization and reducing air pollution among cement facilities, and found that five of the top 11 facilities emitting well above the median levels of PM2.5 and CO2 per year are located in areas where 66–100% of the population within a three-mile radius meet Justice40 criteria.[12] They conclude that "such sites are top candidates for early investment in technologies that substantially reduce both carbon and air pollution emissions."

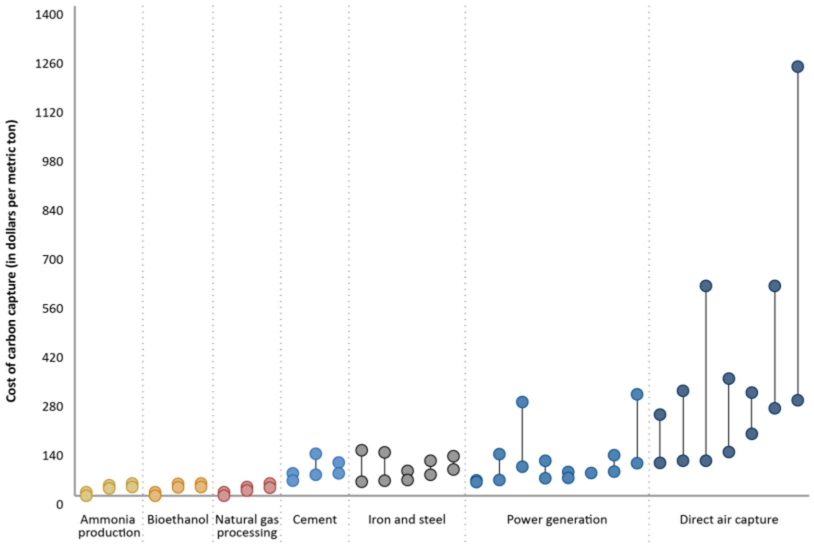
Many studies of social attitudes and preferences have confirmed a community preference for fossil fuels, especially in areas of the country that produce and use oil, coal, and natural gas[13], those that will export fossil fuels[14], or areas where energy insecurity (such as high prices or shortages of supply) is perceived to be greater.[15] [16] Nevertheless, a body of evidence is emerging that these attitudes are beginning to change and that decarbonization efforts, especially those that focus on renewable energy, may have broader public support than previously thought. Bergquist and colleagues studied data from three longstanding time-series surveys—the National Surveys on Energy and Environment, the Climate Change in the American Mind survey and the Gallup Poll Social Series—and found consistently "strong and temporally stable support for policies that promote renewable energy technologies, as well as policies that prioritize environmental protection over energy extraction."[17] Attari and colleagues documented positive views held by a sample of Americans concerning reducing their own consumption, adopting more carbon-friendly transportation, green policy, and recycling.[18] Crow and Li sampled respondents from three very different communities in the United States—Illinois, Texas, and Vermont—and found that while sense of place determined social views, and those living in places with historical attachment to coal mining had positive attitudes toward fossil fuel, the data revealed that those people had even more positive attitudes toward sustainable energy sources.[19]

4. Revealing barriers, challenges, and risks of industrial decarbonization

Community barriers (obstacles to the achievement of decarbonization goals) and risks (adverse outcomes) exist in juxtaposition to the benefits above. These include uncertainty in technical performance, liability concerns, accidents, as well as high costs of deployment and lack of a mature market. Spatial unevenness, permitting for facilities and pipeline rights of way, as well as lack of skills and workforce development are prominent barriers. Potentially adverse outcomes include environmental impacts, residual emissions, methane or hydrogen leakage, as well as disparities in air pollution and distribution of co-impacts.

One core problem is cost. In 2022, the added cost for capturing carbon dioxide from industrial facilities in the United States was lower than $100 only for ammonia production, bioethanol, and natural gas process. For all other sectors including cement, iron and steel, power supply, and direct air capture, it was substantially more expensive (see Figure 3).

Figure 3: Estimated costs to capture one top of carbon dioxide in the United States across different industrial sectors



Source: [20], used with permission.

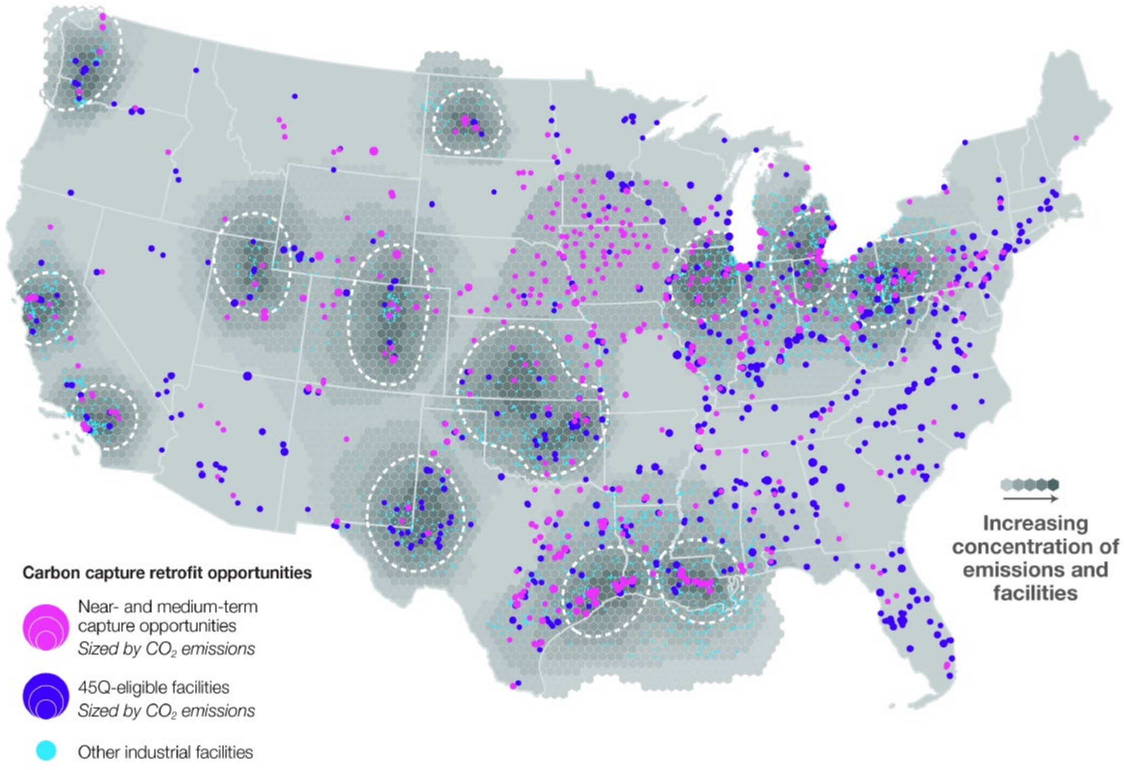
Disparities can be both demographic and spatial. In terms of demographic disparities, given that many industrial facilities reside in communities of color or low incomes, many with population density in very close proximity to sources of high emissions, industrial decarbonization has the potential to worsen disparities in air pollution, rather than to improve them. Colmer and colleagues for instance noted that pollution abatement trends in the United States as a whole have not altered disparities in exposure to PM2.5 pollution.[21] Although total pollution levels have declined, the most polluted census tracts in 1981 remained the most polluted in 2016, the least polluted census tracts in 1981 remained the least polluted in 2016, and the most exposed subpopulations in 1981 remained the most exposed in 2016. The authors conclude that “Overall, absolute disparities have fallen, but relative disparities persist.” [22] Wang and colleagues reached a similar conclusion in their assessment of the Biden Administration’s Justice40 Initiative Climate and Economic Justice Screening Tool (CEJST). They noted that application of CEJST to guide ambient air pollution emission reductions may eliminate the modest exposure disparities by income, but for disadvantaged communities it does not ameliorate the frequently larger disparities by race-ethnicity.[23]

Moreover, given the historical pattern of heavy industrial facilities being located in communities of color, they have come to be opposed by Black, Indigenous, and people of color (BIPOC) residents. As Bukirwa and colleagues write: “Given this past and persistent discrimination, it is understandable that communities are wary and skeptical of heavy industry development, even if the intent is a cleaner energy future. There are legitimate reasons why communities are skeptical of replacing unabated fossil fuels with hydrogen, including health, safety, environmental, and water usage concerns, and that certain hydrogen production methods will perpetuate some fossil fuel industries.”[24] Environmental concerns can therefore become social and political concerns over future development.

Spatial disparities exist as well. Synder writes that “there are a small number of U.S. counties that appear to be highly vulnerable to decarbonization, and this suggests that policymakers could take a spatially-targeted approach to mitigating the socioeconomic impacts.”[25] The Great Plains Institute identified prime candidates for carbon capture retrofitting at industrial facilities and power plants (See Figure 4 Panel a), for carbon storage (panel b), for and for hydrogen (panel c). they identified 542 distinct facilities as attractive locations for carbon capture retrofit, and found that near-term candidates for capture are largely clustered in 14 regional hubs—making it spatially uneven across the country. Storage capacity is also locally distributed unevenly, with the optimality of carbon injection sites prone to heterogeneity in storage permanence, storage capacity, transport costs, restrictions on land use, and community acceptance—greatly restricting potential across most of the country. Hydrogen and ammonia production and industrial fuel use are also concentrated in these 14 clusters.

Figure 4: Carbon capture retrofit opportunities (panel a), storage capacity (panel b), and hydrogen potential (panel c) among 14 regional hubs in the United States

a



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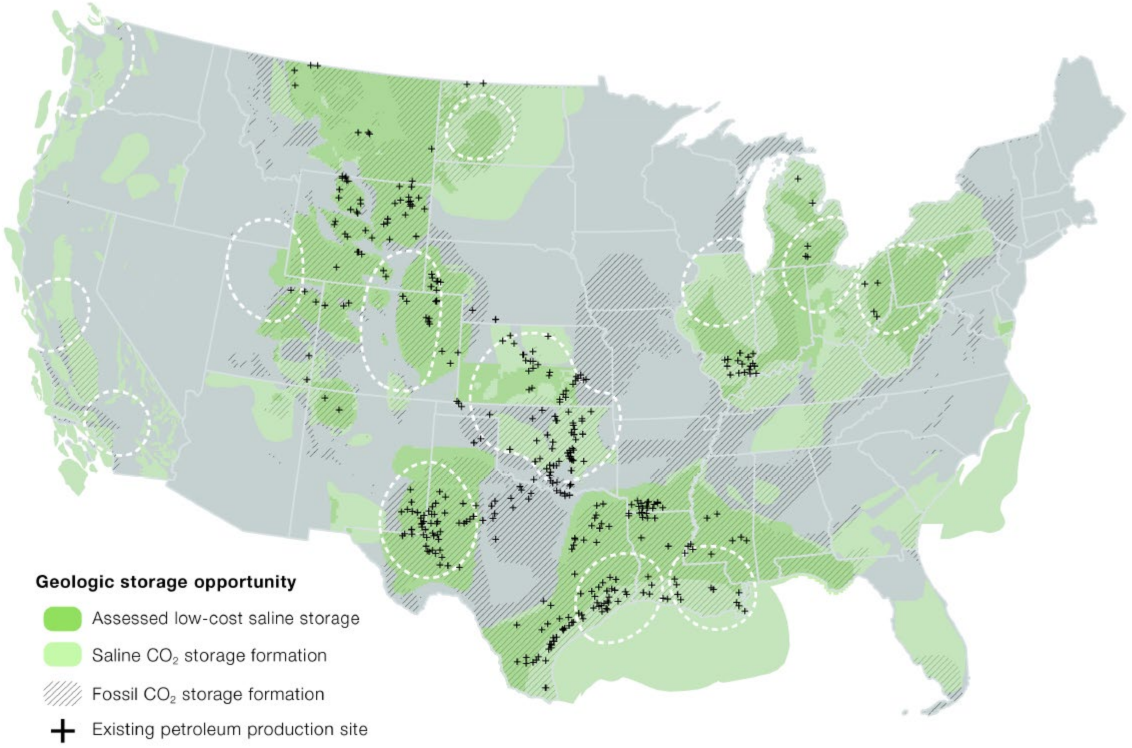

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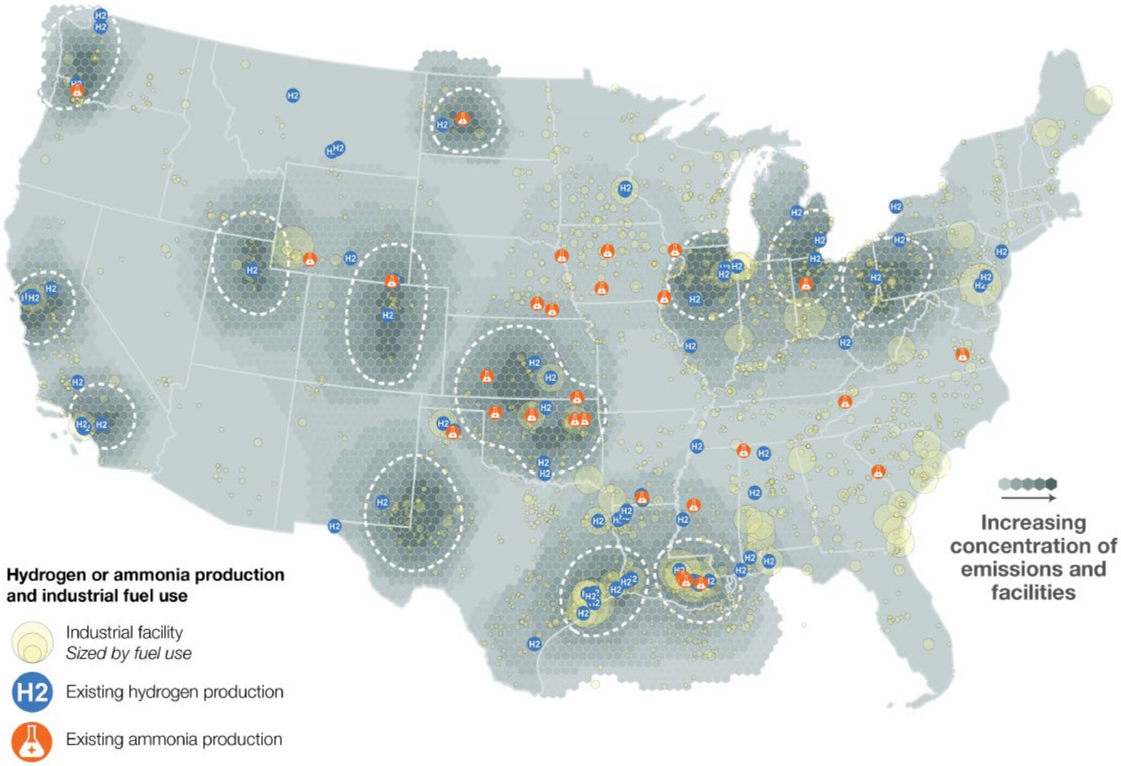
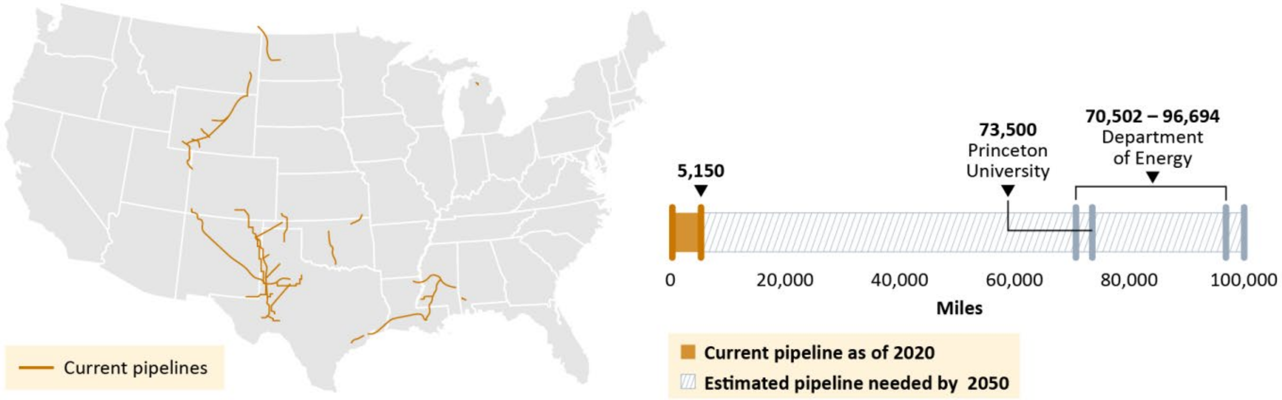


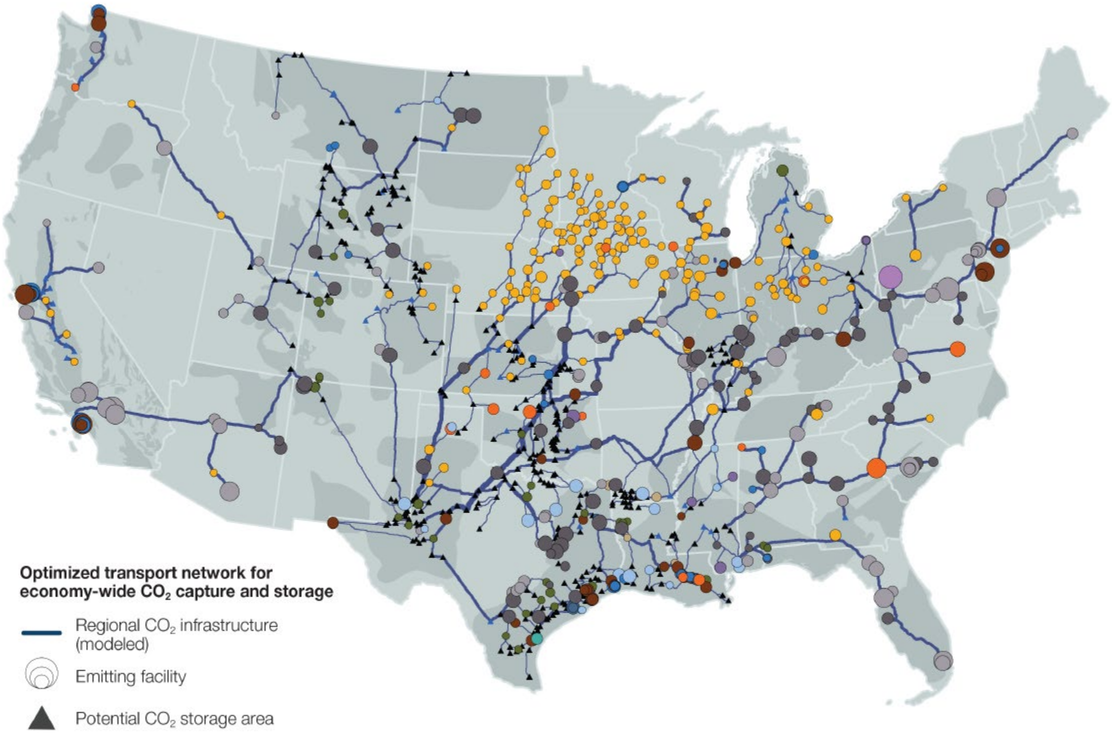
Source: [26], used with permission.

Workforce skills, training, knowledge and employment opportunities present another risk. Human capital, defined broadly as covering the full range of "'skills, knowledge, and capabilities of the workforce"[27], is integral to achieving the socioeconomic goals of industrial decarbonization[28]. As the U.S. Department of Energy concluded, "The full range of the workforce needed across all industrial subsectors will require a spectrum of new skillsets to support successful implementation of decarbonization technologies and improved carbon accounting at a broad scale," meaning that "engaging state, local, and tribal communities and other stakeholders, with a particular focus on disadvantaged communities, will be critical to ensuring the benefits and impacts of industrial decarbonization are equitably distributed."[29] However, ensuring that this skilled workforce exits is a major "crosscutting barrier." [30]

Pipeline challenges could be particularly salient. Putting its spatial unevenness aside for the moment, even to achieve decarbonization the 14 clusters or regional hubs shown in Figure 3 one would need a truly massive buildout or long-distance regional carbon pipelines, which can deliver captured carbon dioxide to optimal storage sites (see Figure 5). As of 2020, the United States approximately 5,000 miles of carbon dioxide pipelines, as reported to the Pipeline and Hazardous Materials Safety Administration. Yet to achieve widespread deployment of carbon capture and storage, at least 73,500 to 96,600 miles of new pipelines would need to be built.

Figure 5: An optimized transport network for carbon dioxide storage across 14 regional clusters in the United States





Source: Top panel is from [31], bottom panel from [32], used with permission.

Erecting such a substantive pipeline network would be a significant challenge. Both history and recent experiences affirm this point. During the construction of the first major interstate oil pipeline in the United States, the Big Inch Pipeline, in 1942, developers had to acquire through eminent domain about 300 of the 7,500 properties, and court battles and challenges lasted years and occurred in multiple states.[33] Concerns are exacerbated by high profile pipeline accidents such as the natural gas pipeline explosion which killed 12 campers near Carlsbad, New Mexico in 2000, and the 2006 BP Alaska oil pipeline leaks, which temporarily halted North Slope oil production.[34] [35]

More recently, in the Illinois Basin, one of the most significant sources of carbon storage in the Mt. Simon sandstone, Wolf Carbon Solutions had to withdraw their permit application in late 2023 to transfer carbon from Iowa to Illinois; it also had its pipeline permits denied in South Dakota and North Dakota.[36] Resistance over such pipelines was strong and involved landowners well as civil society group Citizens Against Predatory Pipelines. Their opposition was grounded in concerns about eminent domain but also stored carbon damaging groundwater supplies or pipeline construction degrading farmland. Analogously, even though Summit Carbon Solutions' Midwest Carbon Express CO2 Pipeline in Iowa, Minnesota, Nebraska, and North and South Dakota secured $1 billion in investment, North Dakota's Public Service Commission unanimously rejected the siting permit. [37] Reasons included "insufficient plans from the developer to address environmental impacts and public safety risks, such as potentially unstable geologic areas and concerns from landowners." [38] In Minnesota, new tar sands pipelines have repeatedly had their permits denied and projects cancelled over concerns about water contamination.[39] In Virginia, concerns over the Atlantic Coast Pipeline (for natural gas) resulted in half a decade of lawsuits, arrests, and injunctions.[40]

These are not isolated incidents. Hess and colleagues organized an original dataset of gas pipelines in the United States, a potential analogue for carbon pipeline construction, and noted that coalitions rise to oppose and stop pipelines in more than *half* of the cases (see Table 1).[41] Pipeline projects can be cancelled for a variety of reasons including legal uncertainty, inconsistency with stated policies, or permitting concerns. McKenzie and colleagues surmise that pipelines overcome such opposition only when strong stakeholders such as labor unions become involved to limit avenues for formal opposition.[42]

Table 1: Cases studies of strong pipeline opposition resulting in a no-build outcome

Pipeline	Developer's rationale	Proximate events
Access Northeast	Inconsistent state energy policies	Massachusetts Supreme Court blocked utilities from charging ratepayers to finance construction. Other state agencies and legislatures were also engaged in blocking decisions.
Atlantic Coast	Legal uncertainty	The developers cited one specific federal court case that created ongoing uncertainty, but there were other federal court cases pending and unresolved.
Bluegrass	Lack of customer commitments	State courts ruled against the right of eminent domain for this case; state legislature bills to limit eminent domain were introduced but not passed at the time of the decision.
Constitution	Lack of risk-adjusted return	State agencies were engaged in ongoing legal battles to withhold certification for the pipeline.
Northeast Energy Direct	Lack of customer commitments, lack of state regulatory procedures regarding binding contracts	Local and state governments continued to litigate over land access. Strong opposition from U.S. Congressional representatives and senators.
Pacific Connector and Jordan Cove	Lack of state government permits	State government agencies denied certification. FERC upheld state's denial of clean water certification.
Palomar Bradwood Landing	Lack of customer need due to changing economic circumstances	Federal court vacated the FERC approval. State government agencies denied permits and certification.
PennEast	Challenges in obtaining state government permits	Litigation with state government over eminent domain for public land. State government did not grant certification.
Via Verde	Developer (public power agency) responds to	High public opposition led the governor to reverse position and end support prior to an election.

	opposition with alternatives to solve electricity power needs	

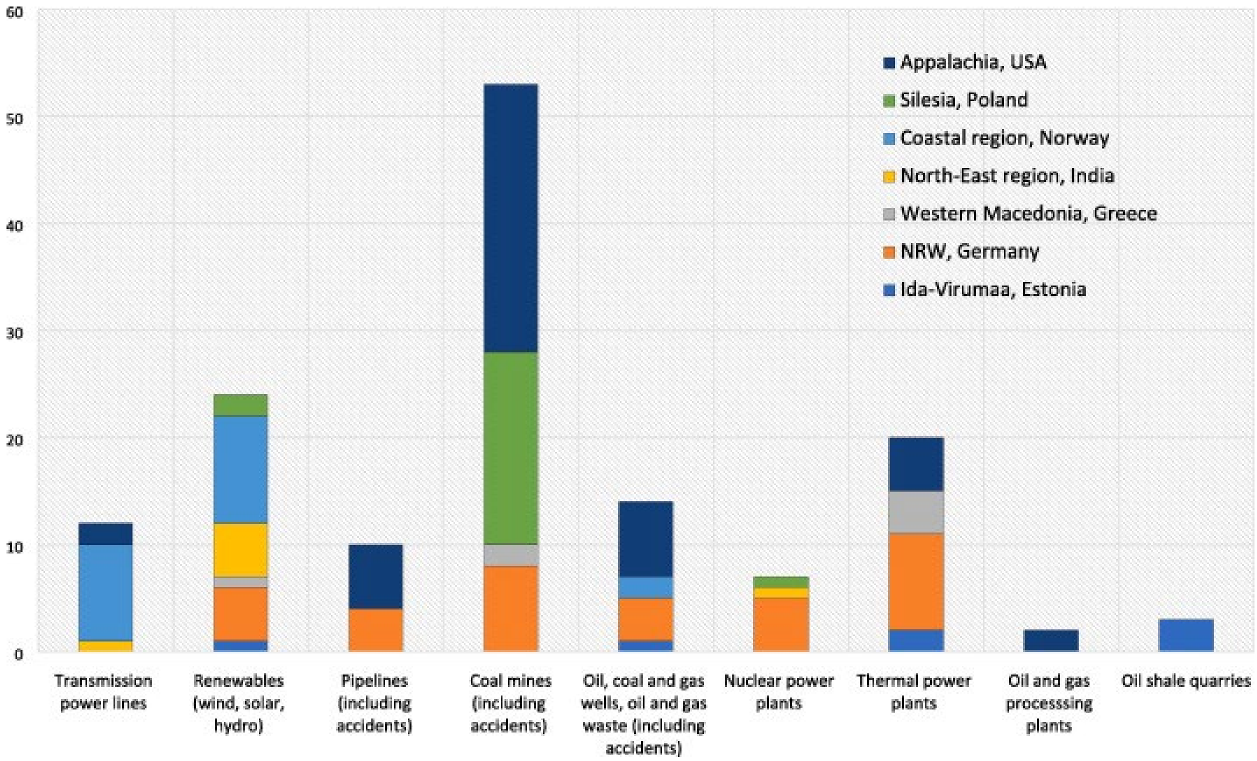
Source: [43]

Some of the most well-developed evidence on the social acceptance of energy transitions in the United States involves the recent industrialization associated with the rapid expansion of natural gas and oil production via fracking since about 2010[44], which reminds us that public attitudes towards new energy systems are never only positive or negative, or static—they are instead dualistic and dynamic.

Even industrial decarbonization processes that promote renewable energy may not escape opposition. Arent and colleagues warn that variations in social equity, economic and sociocultural constraints, the availability of energy resources, and supply chain dynamic swill all present a range of challenges to decarbonization. As they concluded: "The transition to a net zero economy is inhibited by cultural and political factors and social inequities. PV, EV, and clean energy technologies that are available only to the more affluent, nurture public opposition, engender popular resentment and resistance, or reproduce and exacerbate inequality, are unlikely to prove sustainable by any economic, social, or ecological metric."[45] Susskind and colleagues examined 53 utility-scale renewable energy projects and found that opposition from community groups stopped 4,600 MW of capacity being built; across these cases, about 30% stemmed from concerns over procedural equity and failing to meaningfully engage with community members.[46]

Sovacool and colleagues examined 130 case studies of opposition to energy infrastructure, including renewable energy, transmission lines, and oil and gas infrastructure, with multiple examples from the Appalachian region of the United States (see Figure 6).[47] One finding is that that renewable energy and low-carbon infrastructures are frequently protested across their dataset, they are protested in every country examined, and renewables come only after coal mines in terms of the frequency of protest against them. Nuclear power facilities are protested more than oil and gas processing plants or oil shale quarries. This is troubling insofar as the goals of industrial decarbonization depend on low-carbon technologies, but such options appear to germinate in stronger forms of social opposition. Public perceptions and social opposition against energy infrastructure can be further amplified misinformed views on oil and natural gas (in terms of overestimating or underestimating benefits or risks), as well as political affiliations that are identified as conservative or liberal, all of which can further fracture visions of a future decarbonized energy system.[48]

Figure 6: Opposition and community mobilization against energy infrastructure (N=130 cases)



Source: [49]

Indeed, a more recent assessment of industrial decarbonization pathways identified no less than seven other distinct crosscutting barriers (not outright opposition).[50] These are:

1. Challenging economics with long payback periods and a subsequent lack of first-of-a-kind projects that are at very early levels of technological readiness, even after incentives from the Inflation Reduction Act are taken into consideration;
2. Operational roadblocks delaying implementation of decarbonization retrofits, such as alignment of decarbonization investments to asset downtime windows;
3. Overreliance on a small portfolio of technologies with relatively low deployment rates (e.g., carbon capture and storage, hydrogen);
4. Nascent ecosystem of value chain partners and lack of enabling infrastructure (e.g., carbon dioxide and hydrogen pipelines);
5. Capital formation challenges due to relatively lower returns on investment, higher volume of capital needed, perceived risks of retrofits and a threat to existing assets;
6. Limited ambition (to date) among regulators as well as producers and consumers for low-carbon industrial products;
7. Inconsistent public acceptance due to environmental and human health risks, environmental justice, and labor concerns.

The Government Accountability Office also identified three challenges facing industrial carbon capture and utilization deployment in the United States[51]:

1. Cost, as deploying carbon capture still represents an added cost to doing business and offers few opportunities to generate revenue for firms;

2. Infrastructure, as widespread deployment will require transport and storage but these issues remain hampered by land access and rights of way among transport corridors;
3. Community engagement, as previously local opposition has led to the cancellation or relocation of projects.

Grubert and Hastings-Simon independently examined challenges for national decarbonization pathways in the United States, inclusive of industrial pathways, and noted "significant challenges associated with the fact that both activities are intended to create national (and global) benefit at the expense of local harms, and that host and prospective host communities are likely to understand, and oppose, concrete and easily communicated negative impacts."[52] Interestingly, all three of these studies note that challenges to industrial decarbonization cut across technical and non-technical dimensions and involve technology but also governance, social acceptance, and economics.

5. Future research gaps and recommendations

Based on the review, this final section proposes six research gaps and data needs, which are summarized by Text Box 1. These include (1) developing new conceptual frameworks specific to industrial decarbonization, (2) broadening the consideration of co-benefits, (3) undertaking new data collection via surveys, (4) harness new forms of evidence especially qualitative evidence, (5) consider further portfolio approaches and crosscutting issues, and (6) appreciate the stakeholder networks and regional governance dynamics of industrial decarbonization.

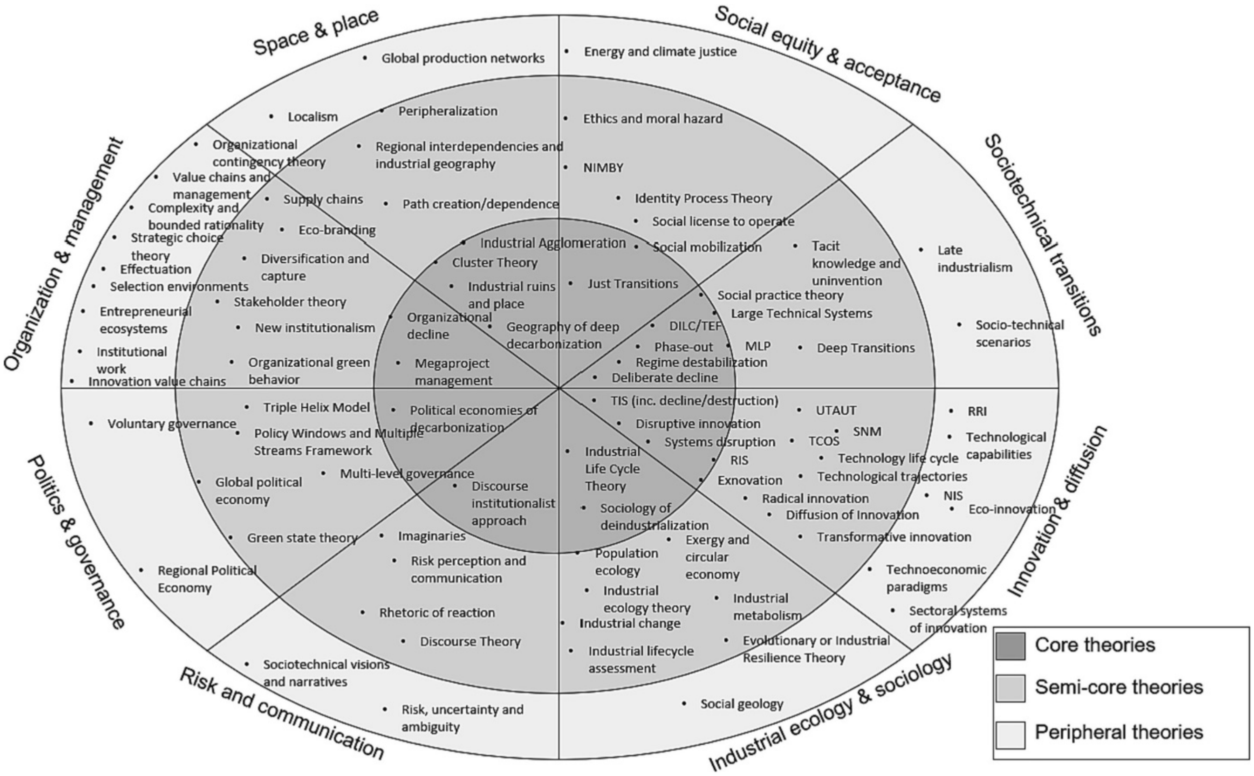
Text Box 1: Future research gaps and data needs generated by the review

1. **Develop theories and conceptual frameworks specific to industrial decarbonization.** It is difficult to find conceptual approaches or frameworks specifically created for net-zero industry. Therefore, new heuristics may be warranted to help guide research, analysis, and policy.
2. **Broaden consideration of co-benefits.** Existing research focuses mostly on air pollution, health, and carbon emissions, but may miss other co-impacts across political, social, and economic dimensions.
3. **Utilize representative national or local surveys specific to industrial decarbonization, rather than decarbonization generally.** This can include sector-specific surveys covering various modes of industry, or specific forms of transport such as carbon pipelines.
4. **Move beyond models and surveys to a stronger evidence base.** Other forms of evidence include stated preference techniques such as community interviews, household diaries, or focus groups, or revealed preference techniques such as embedded ethnography, naturalistic observation, or spatial analysis.
5. **Better understand the portfolio aspects of technical industrial decarbonization options and crosscutting trade-off risks.** Options differ in their risk, uncertainty, investment needs, intersections across sectors, and timing.
6. **Appreciate the stakeholder networks and regional governance dynamics of industrial decarbonization.** This may be done via a multi-actor, multi-technological, multi-scalar approach via hubs and clusters.

Source: Author.

Firstly, theories and frameworks specific to industrial decarbonization or especially industrial decarbonization in the United States are rare to nonexistent. One expert guided review identified more than 80 potential theories but noted that only a small sample of 25 were specific to industrial decarbonization (see Figure 7).[53] Few to none of these seem to have been applied yet in a United States context. Instead, the literature seems abundant with more general frameworks such as environmental justice, policy windows or energy justice being applied in an industrial context. The only notable exception is Upham and colleagues explicit development of a Just Transitions framework for industrial decarbonization (see Table 2).[54] However, this has only been applied so far to three communities in the United Kingdom: Grangemouth, the Northwest Cluster (Merseyside) and South Wales.

Figure 7: Core theories and conceptual approaches relevant to the study of industrial decarbonization



Source: [55], used with permission.

Table 2: Themes and issues for consideration from an industrial decarbonization Just Transitions framework

Themes	Issues for consideration
Politics, space and institutions	
Justice	Rights of public participation and redress; degree of social equity (income, information)
Democracy	Worker representation on company boards; labor unions and their role; statutory powers of spatial planning bodies
Financialization	Macro-economic policy; patterns of share ownership; employee shares; influence of various types of investor and financial instruments
New processes and procedures	
Legal recognition of public concerns	Definition of what is material in planning law; processes for taking public concerns into account

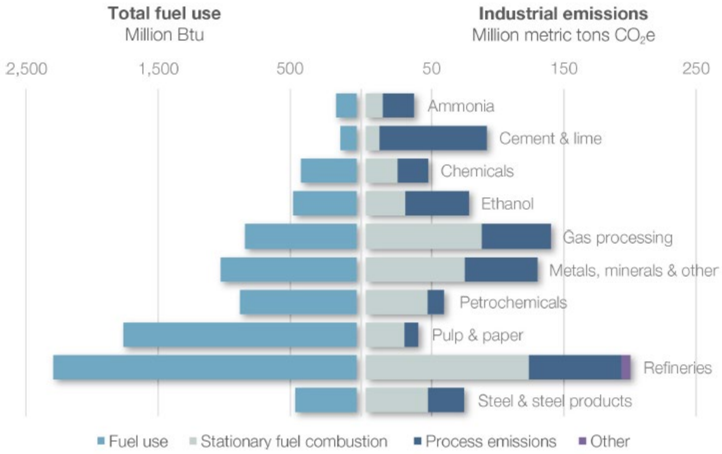
Community-based planning	Processes for community engagement at different stages of policy and project life cycles
Community capacity enhancement	Provision of resources to communities to support meaningful engagement
Life cycle impact assessment	Evaluation and response to indirect, spatially and temporally distant impacts
Acceptance and resistance	
Environmental values	Degree of prevalence of different types of environmental value in affected communities
Perceived loss of amenity	Degree of perception of any amenity loss or gain
Pre-existing politics and trust	Public opinion of companies and developments, past, present and future
Perceptions of a just process	Public opinion of planning engagement processes, past, present and future

Source: [56].

Secondly, the bulk of co-benefits research so far has centered on air pollution and carbon emissions. However, further work should explore other co-benefits or co-impacts such as jobs, resilience, innovation, trade competitiveness, and more. Sovacool and colleagues found 128 co-benefits for four low-carbon transitions in Europe (smart meters in Great Britain, nuclear power in France, solar energy in Germany, and electric vehicles in Norway), and noted that some were political or even social.[57] Building on this work in a follow up study, Sovacool et al. applied sociotechnical thinking to include a diffuse array of possible co-impacts across different dimensions related to carbon removal and net-zero transitions: Financial and economic co-impacts such as the expansion of markets, business models, government revenues, and carbon credits (among others); socioenvironmental co-impacts such as protection of habitats, forests, oceans or species, or the provision of decent work and high paying jobs; technical co-impacts such as the improved performance of systems, disruptive or positive innovation patterns for a sector, enhanced efficiency, or positive and negative learning and experimentation; political and institutional co-impacts such as the achievement of policy goals (relating to industrial strategy, equity and leveling up, or energy security) or the creation of a moral hazard.[58] Such broad and multidimensional assessments of co-impacts could be applied to industrial decarbonization.

Thirdly, much of the extant social acceptance work is not specifically on industrial decarbonization, but instead on decarbonization more generally with comparison across different pathways (transport, buildings, electricity supply, etc.) or visions. Nationally or locally representative surveys on industrial decarbonation *specifically*, not broader issues like decarbonization as a whole, are rare, and could involve very specific sectors such as cement and concrete, oil and gas refining, chemicals manufacturing, steel, food and beverages, paper and pulp, ceramics, glass, and the generation of fluorinated gases (F-gases), or large sources of industrial emissions such as ammonia, ethanol, petrochemicals or metals and minerals (See Figure 8). Specific social acceptance work on *carbon* pipelines would also be apt, given that most existing work covers other types of pipelines (oil, natural gas, oilsands, shale gas) in the United States, or carbon pipelines or infrastructure in other countries, such as Australia,[59] Germany[60] [61], the Netherlands[62], or Europe as a whole[63] [64]. The Congressional Research Service has cautioned that almost "no research … examines public attitudes specifically concerning CO2 pipelines" in the United States.[65] The International Energy Agency has similarly warned that "a common perception across stakeholder groups that siting CCS facilities, including pipelines, will be a major challenge."[66] Energy industry experts have their own worry that carbon pipelines would face growing public opposition not only in affluent communities but across a wide range of socioeconomic groups.[67]

Figure 8: The largest industrial sources of energy use and emissions in the United States

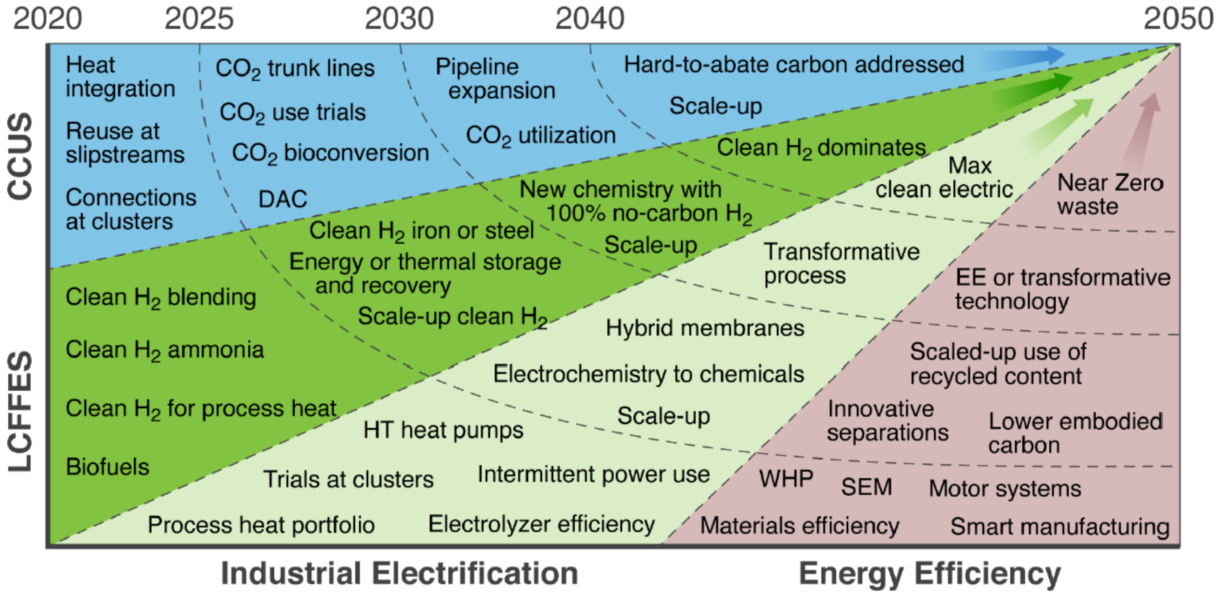


Source: [68], used with permission.

Fourthly, much of the existing social science research on industrial decarbonization seems to be grounded in models, scenarios, or surveys. It would do the community well to move beyond these instruments, especially surveys alone, to utilize other stated preference research designs such as focus groups, community or expert interviews, household diaries, or expert elicitation workshops, or perhaps to triangulate stated preference research designs with revealed preference techniques such as ethnography and naturalistic observation. These broader methods would ensure that more comprehensive place-based assessments of equity and justice are possible as well as documenting the real lived experiences of people engaged in industrial decarbonization, including those from frontline communities and workers. New informational tools such as online inventories of coping strategies, citizens assemblies, collecting energy biographies, or citizen science data collection are possible, and national labs, universities, local or state planning offices, and NGOs can collaborate with industry and trusted community stakeholders to collect and share data responsive to community concerns, a finding also endorsed by ACEEE, especially when coupled to spatial analysis.[69] The U.S. Department of Energy also recommends more research that can comprehend and even come to address public concerns through Community Benefits Plans, market adoption of Community Benefits Agreements, Project Labor Agreements, and responsible business and labor practices.[70]

Fifthly, how to develop optimal portfolios of low-carbon technologies remains an innovation management challenge, given the uncertainties and risks involved. Balancing innovation investments is a significant dilemma for entrepreneurs and policymakers, because some innovations are already available as early opportunities now, such as process heat solutions or producing hydrogen from wind electricity, but others only exist as options possible after 2030 or 2040, such as hybrid membranes or zero waste systems (see Figure 9). The challenge is to develop a portfolio of synergies within and across subsectors and pillars, and across different phases of the innovation journey. Technical options differ in their risk, uncertainty, investment needs, intersections across sectors, and timing, which makes both research and deployment prone to tradeoffs. Zhu and colleagues already emphasize the potential for tradeoffs when noting that building electrification would achieve about 15% greater total health benefits than the truck or transport electrification, but that transport electrification would benefit disadvantaged communities more.[71] Similar tradeoffs will likely exist within and between industrial decarbonization pathways.

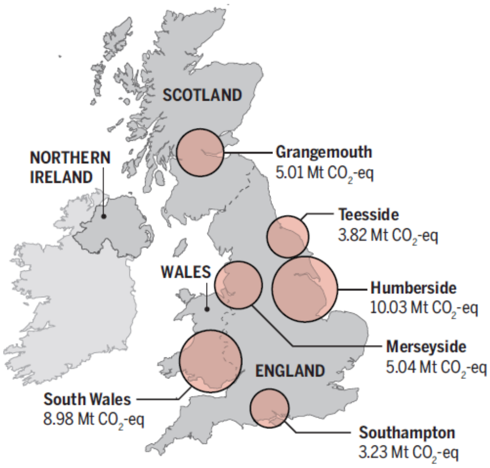
Figure 9: Research development and demonstration investments needed for industrial decarbonization

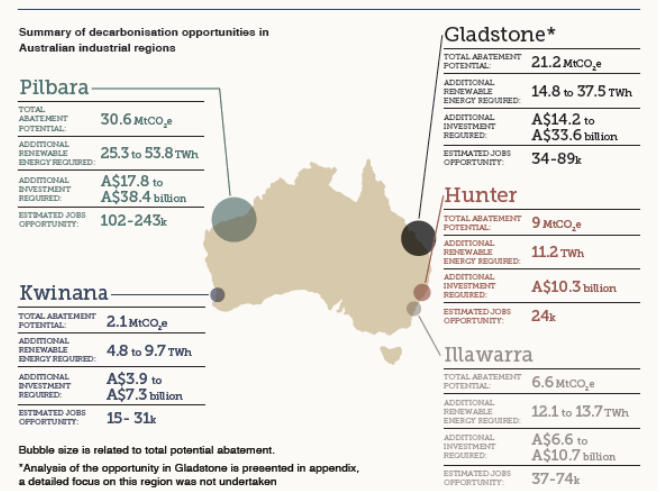


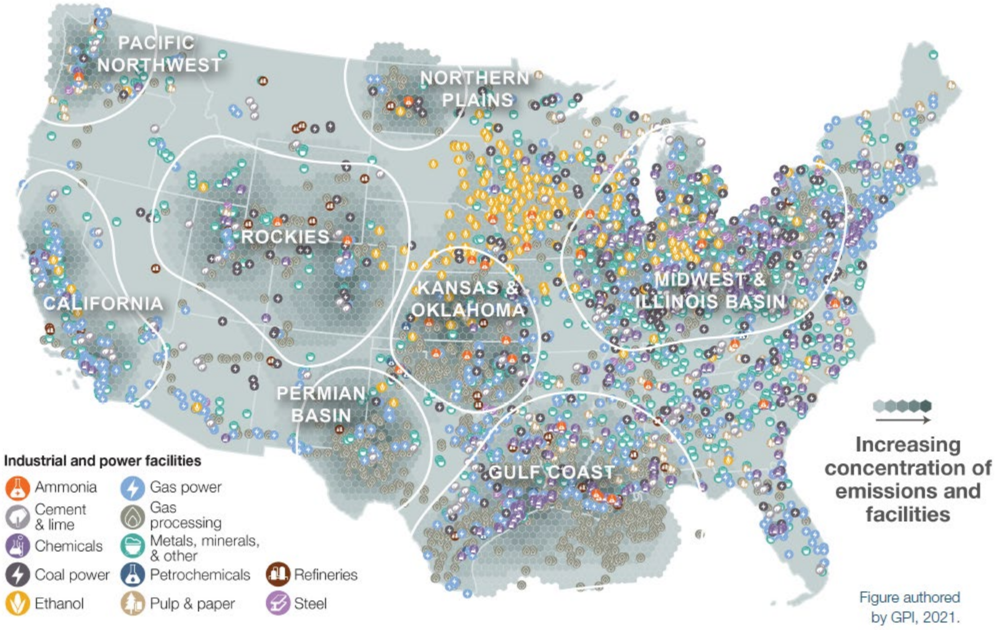
Source: [72]. CCUS = carbon capture utilization and storage. LCFFES= Low carbon fuels, feedstocks, and energy sources.

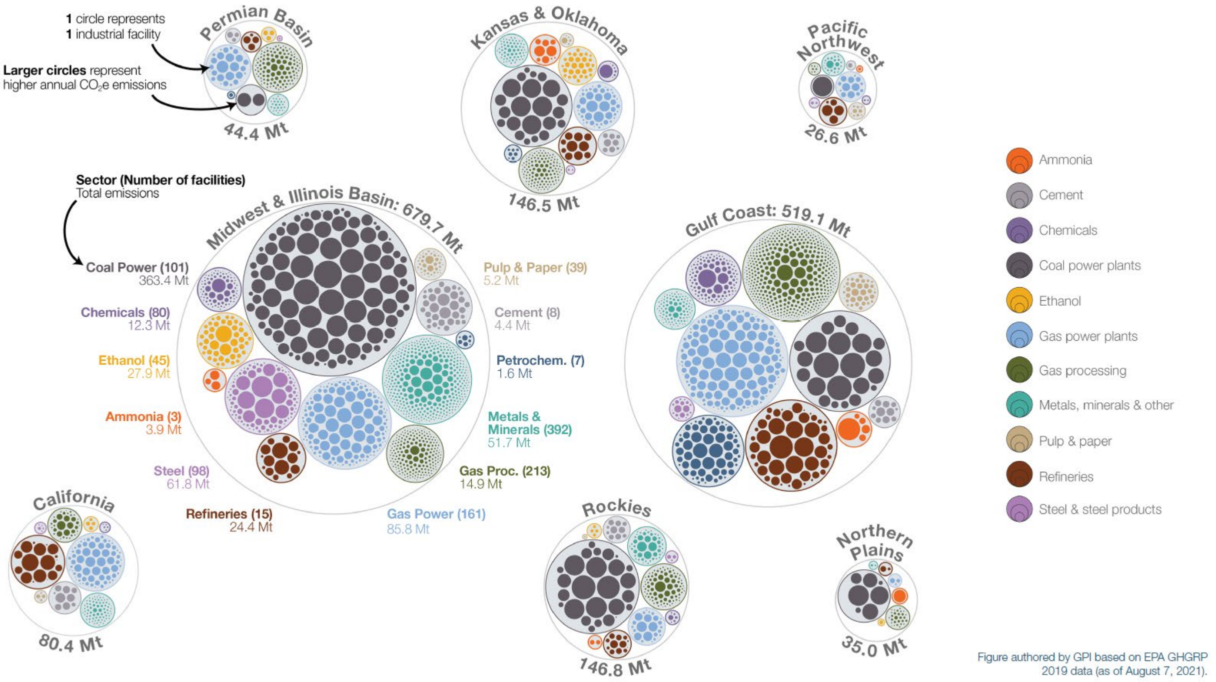
Sixth and lastly, research is needed to advance the understanding of actor coalitions and the regional governance dynamics of industrial decarbonization, especially as infrastructures become coupled spatially and technologically. Cluster and hub approaches are novel and promising because they capture the multi-sectoral, muti-technological, and place-based nature of decarbonization (see Figure 10). This avoids tackling efforts only via isolated technologies (e.g., hydrogen only) or isolated industrial sectors (e.g., cement only) or processes (e.g., heating only). Instead, efforts focus on all technologies, industrial sectors, and energy processes within a single, confined geographic area.

Figure 10: Visualizing net-zero clusters or hubs in Australia, the United Kingdom and United States


SCOTLAND
NORTHERN IRELAND
Grangemouth
5.01 Mt CO_2-eq
Teesside
3.82 Mt CO_2-eq
WALES
Humberside
10.03 Mt CO_2-eq
Merseyside
5.04 Mt CO_2-eq
ENGLAND
South Wales
8.98 Mt CO_2-eq
Southampton
3.23 Mt CO_2-eq


Summary of decarbonisation opportunities in Australian industrial regions
Pilbara
TOTAL ABATEMENT POTENTIAL: 30.6 $MtCO_2e$
ADDITIONAL RENEWABLE ENERGY REQUIRED: 25.3 to 53.8 TWh
ADDITIONAL INVESTMENT REQUIRED: A$17.8 to A$38.4 billion
ESTIMATED JOBS OPPORTUNITY: 102-243k
Kwinana
TOTAL ABATEMENT POTENTIAL: 2.1 $MtCO_2e$
ADDITIONAL RENEWABLE ENERGY REQUIRED: 4.8 to 9.7 TWh
ADDITIONAL INVESTMENT REQUIRED: A$3.9 to A$7.3 billion
ESTIMATED JOBS OPPORTUNITY: 15- 31k
Gladstone*
TOTAL ABATEMENT POTENTIAL: 21.2 $MtCO_2e$
ADDITIONAL RENEWABLE ENERGY REQUIRED: 14.8 to 37.5 TWh
ADDITIONAL INVESTMENT REQUIRED: A$14.2 to A$33.6 billion
ESTIMATED JOBS OPPORTUNITY: 34-89k
Hunter
TOTAL ABATEMENT POTENTIAL: 9 $MtCO_2e$
ADDITIONAL RENEWABLE ENERGY REQUIRED: 11.2 TWh
ADDITIONAL INVESTMENT REQUIRED: A$10.3 billion
ESTIMATED JOBS OPPORTUNITY: 24k
Illawarra
TOTAL ABATEMENT POTENTIAL: 6.6 $MtCO_2e$
ADDITIONAL RENEWABLE ENERGY REQUIRED: 12.1 to 13.7 TWh
ADDITIONAL INVESTMENT REQUIRED: A$6.6 to A$10.7 billion
ESTIMATED JOBS OPPORTUNITY: 37-74k
Bubble size is related to total potential abatement.
*Analysis of the opportunity in Gladstone is presented in appendix, a detailed focus on this region was not undertaken


PACIFIC NORTHWEST
NORTHERN PLAINS
ROCKIES
CALIFORNIA
KANSAS & OKLAHOMA
MIDWEST & ILLINOIS BASIN
PERMIAN BASIN
GULF COAST
Industrial and power facilities
Ammonia
Cement & lime
Chemicals
Coal power
Ethanol
Gas power
Gas processing
Metals, minerals, & other
Petrochemicals
Pulp & paper
Refineries
Steel
Increasing concentration of emissions and facilities
Figure authored by GPI, 2021.



Source: Top panel from[73] [74] , bottom panel from [75], used with permission.

A cluster approach enables the decarbonization of regions where industrial activity is concentrated along with carbon emissions, energy and transport infrastructure, and even planning authority or ambition. A cluster approach also recognizes the distinct industrial profiles and networks of existing hubs, meaning each network can play to its strengths as it decarbonizes. It lastly appreciates that decarbonization is a multi-actor, multi-sectoral, multi-technological and place-based phenomena.

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