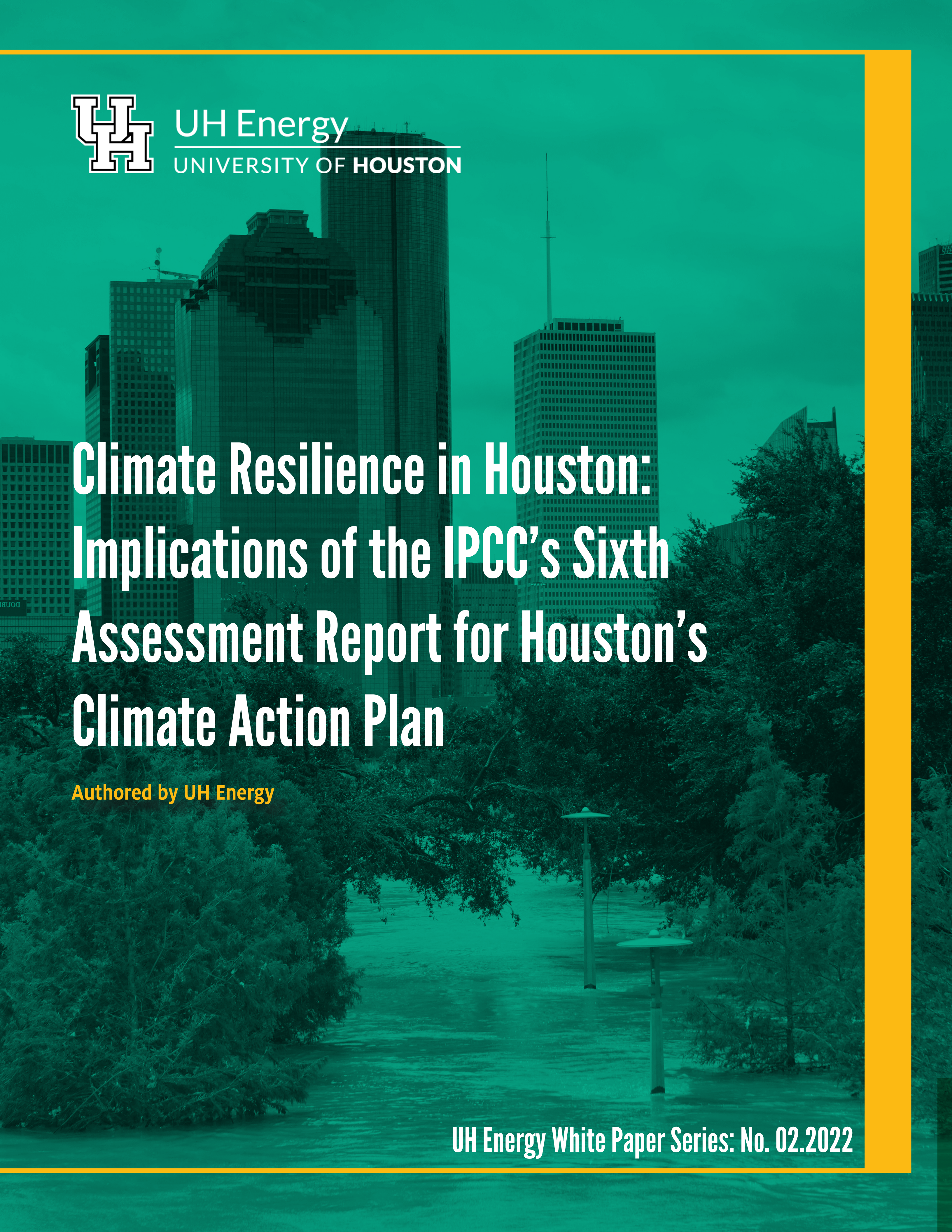

UH Energy
UNIVERSITY OF HOUSTON

Climate Resilience in Houston: Implications of the IPCC's Sixth Assessment Report for Houston's Climate Action Plan

Authored by UH Energy

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White Paper Contributors

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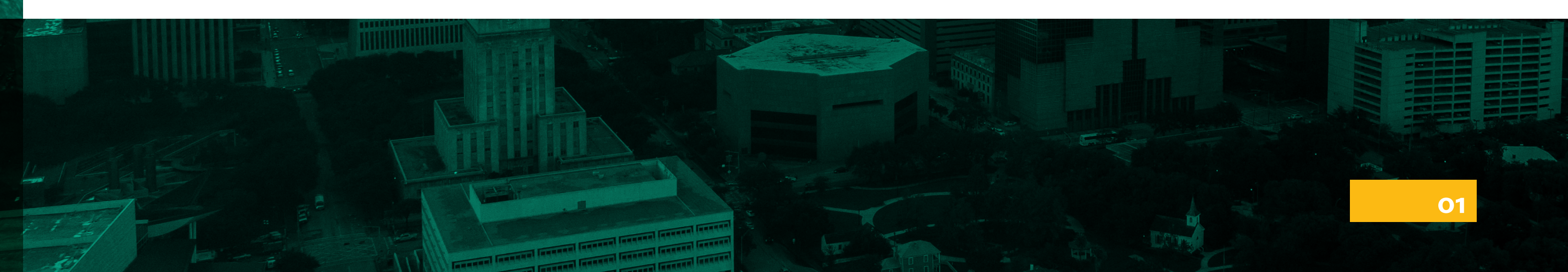


EXECUTIVE SUMMARY

Houston, the nation's fourth largest and most racially diverse city, has undertaken the development of a Climate Action Plan (CAP) and a Resilient Houston Strategy (RHS) in response to a high frequency of natural disasters, including Hurricane Harvey in 2017. These plans include targets and actions to reduce the impacts of climate change, build climate resilience, mitigate greenhouse gas emissions, and lead the energy transition while allowing the people of Houston to live in a healthy, equitable, sustainable, inclusive and affordable city.

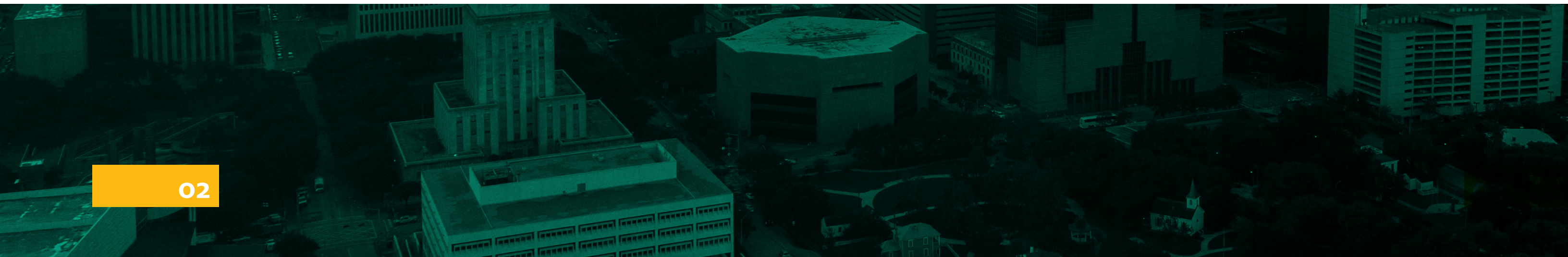
The recent Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) underscored that vulnerable populations, including communities that are economically disadvantaged and those of color will face disproportionate impacts of climate change. We discuss the implications of the IPCC Report for Houston's economy, energy infrastructure, and climate resilience efforts, in addition to the opportunities and challenges this presents for the city and its people. Key recommendations include:

1. Addressing carbon management in conjunction with energy reliability, and actively reducing methane emissions by ensuring the integrity of the natural gas infrastructure and eliminating venting;

2. Regular assessment of climate risks including a timeline for achieving the goals and key milestones, a description of the city's efforts to allocate funds towards these priorities, and the coordinated efforts required for effective and broad stakeholder engagement;

3. Boosting resilience efforts against flooding, sea-level rise, and land subsidence, and site-specific mapping and safeguarding of the city's civil and energy infrastructure;

4. Preparing and strengthening the energy workforce through relevant education, upskilling and reskilling opportunities.



" A recent study found that rainfall from Hurricane Harvey was 38% higher due to the impacts of climate change and flooded 50,000 additional homes in the region . The 2022 Social Vulnerability Assessment from UH's Hobby School of Public Affairs found that about 18% of the households impacted by Hurricane Harvey have not recovered five years later. "

INTRODUCTION

As of January 2022, the Greater Houston region had witnessed 26 federally declared national disasters in the last four decades, and a third of these since 2015[1]. In 2017, Hurricane Harvey stalled over the region and the resultant extreme precipitation and flooding led to at least 70 fatalities and economic losses of over $125 billion[2].

While much of the risks associated with natural disasters in Houston can be attributed to its proximity to the Gulf of Mexico and the region's geography, anthropogenic climate change is exacerbating the impacts and frequency of the extreme weather events and natural disasters witnessed by the city. A recent study found that rainfall from Hurricane Harvey was 38% higher due to the impacts of climate change and flooded 50,000 additional homes in the region[3]. The 2022 Social Vulnerability Assessment from UH's Hobby School of Public Affairs found that about 18% of the households impacted by Hurricane Harvey have not recovered five years later[4].

As the region faces new, increased, and frequent threats from climate change, the City of Houston has prioritized climate resilience as one of its key strategies for adaptation and mitigation. In 2020, the City launched two collaborative efforts, the Houston Climate Action Plan (CAP) and the Resilient Houston Strategy (RHS), to address adaptation and mitigation. The CAP[5] has four focus areas, transportation, energy transition, building optimization, and materials management, and three goals for each under the overarching objectives of maximizing climate action and emissions reductions, improving community equity and resilience, boosting the local economy, and achieving carbon neutrality by 2050.

The RHS provides a framework of five goals for Houston to be: a healthy place to live; an equitable, inclusive, and affordable city; a leader in climate adaptation; a city that grows up, not out; and a transformative economy that builds forward by 2050[6]. The city's first Climate Impact Assessment[7], which grew out of the RHS to better evaluate the heat, drought, and precipitation risks faced by the city, summarizes observed and projected changes into 25 climate indicators.

In its 2022 Assessment Report, the City of Houston detailed that of the 29 prioritized actions in the CAP, 24 are in progress (83%), and 5 are paused (17%), while of the 62 prioritized actions in the RHS, 58 are in progress (95%), 3 are paused (3%), and 1 is complete (2%)[7,8].

These approaches, while noteworthy, are likely to require significantly more attention and accelerated addressing because of the results of the Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report[9] released in 2021. The report highlighted that the impacts of anthropogenic climate change will disproportionately impact disadvantaged and vulnerable populations. The impacts, including frequent and more intense heat waves, flooding, increased precipitation, and sea level rise, will be exacerbated in cities, especially coastal communities.

In this white paper, we analyze the implications of the IPCC Report on Houston's economy, energy infrastructure, and climate resilience efforts. We highlight the opportunities and challenges that these evolving climate scenarios present for the city. We discuss the implications of these changes for the state's energy mix, the region's oil and gas industry, petrochemical facilities and infrastructure, and the transportation sector. We also analyze how Houston's changing demographics will exert increased pressure on natural resources and the associated consequences for climate resilience in the city.

KEY FINDINGS OF IPCC's SIXTH ASSESSMENT REPORT & ITS IMPLICATIONS FOR HOUSTON

A key finding of IPCC's Sixth Assessment Report was that the planet has already warmed by 1.1 °C ±0.2 °C) and now warming at a rate of 0.2 °C per decade[7]. Currently, about 20-40% of the global population lives in regions that have already warmed by more than 1.5 °C in at least one season. The report also highlighted that, regardless of the emissions scenario, global warming of 1.5 °C will occur in the 2050 timeframe and that cumulative changes in global surface temperature will range from 1.4 to 5.7 °C by 2100 across emissions scenarios.

For Houston, the direct impacts will include:
• Increases in the average temperature of all seasons compared to a 1971-1990 baseline. By 2100, the average temperature of the hottest day

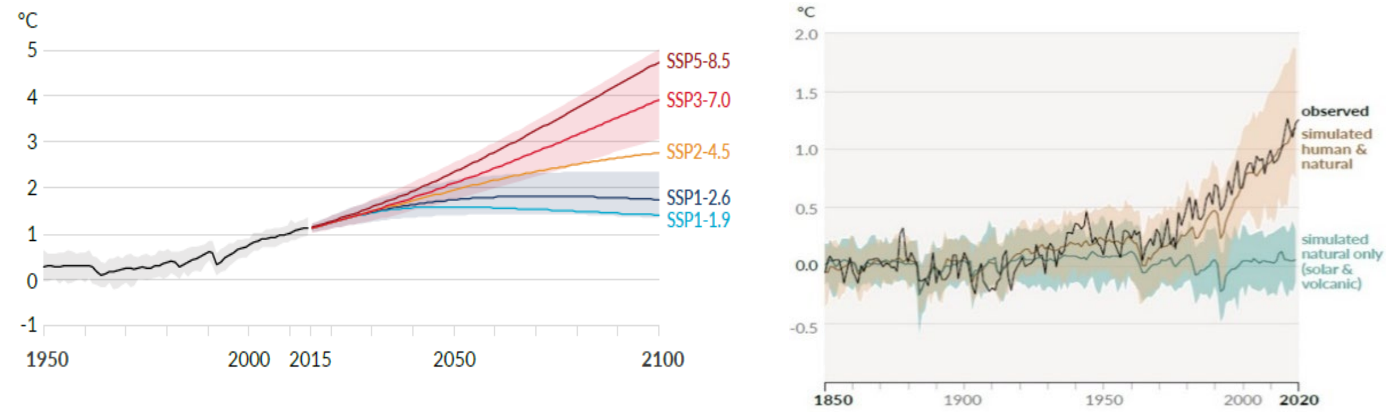


Figure 1. Anticipated change in global surface temperature simulated using human & natural factors between 1850-2100 (left panel) and change in global surface temperature as observed and simulated using human and natural factors, and natural factors only, 1850-2020 (right panel). Source: IPCC Sixth Assessment Report, 2021[7].

is projected to be ~104°F for the lower scenario and~109°F for the higher scenario, with average temperatures of the hottest week projected to be about 101°F for the lower scenario and 105°F for the higher scenario. This will be accompanied with increases in the number of hot days per year with a maximum temperature of above 100°F and the number of warm nights per year with a minimum temperature above 80°F.

• Lengthening of summers, with the summer season beginning earlier and ending later, compared to a 1971-1990 baseline. This will be accompanied by increases in energy demand for cooling for the spring, summer, and fall seasons. By the middle of the century, Cooling Degree Days (CDDs) are projected to increase by 351 or 487 CDDs for the lower and higher scenario, respectively, and 396 or 729 CDDs by 2100 for the summer. This will be accompanied by a decrease in the energy demand for heating buildings in the colder months. Annual cumulative values are projected to decrease by 394 or 534 Heating Degree Days (HDDs) by 2050 and 460 or 739 HDDs by 2100 for the lower and higher scenarios, respectively.

• Longer multi-day heatwaves with an average projected increase of 15.3 or 26.7 days by 2050 for the lower and higher scenarios, respectively, and by 18.8 or 46.6 days by 2100.

• Little change in total annual precipitation but a decrease in summer precipitation and increase in fall precipitation, but greater variability in day-to-day precipitation compared to a 1971-1990 baseline. This will include slight increases in the number of dry days and increasing risk of drought due to soil moisture decreases, as well as increases in precipitation reduction during extreme precipitation events like the wettest three-day period each year. However, increases in the amount of precipitation falling on the wettest 3-days of the year are expected to average 8.6 inches by 2050 and 9 inches by 2100. Additionally, the number of days with precipitation above 4 inches are expected to increase, along with a significant increase in the return period of the 100-year precipitation event.

• Regional sea level change will increase as a combination of global sea level rise, changes in ocean circulation that alter local sea levels, and the subsidence of the coastline compared to a 1971-1990 baseline. Along the Gulf Coast, the land is primarily sinking due to local human activities including the compaction of fine-grained aquifer sediments below the land surface due to groundwater withdrawals. As a result, the relative rate of sea level rise in the Houston area is the second highest in North America.

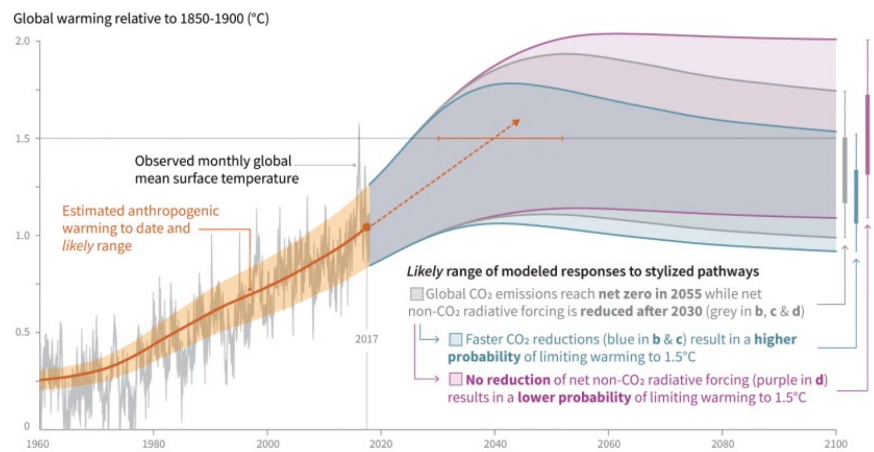


Figure 2. Observed monthly global mean surface temperature change and estimated anthropogenic global warming[1]. Source: IPCC Sixth Assessment Report, 2021[7].

Additionally, the city will experience impacts on public health, safety, and the economy. The energy industry contributes about 25% to Houston's GDP through its direct and indirect impacts[11], and the

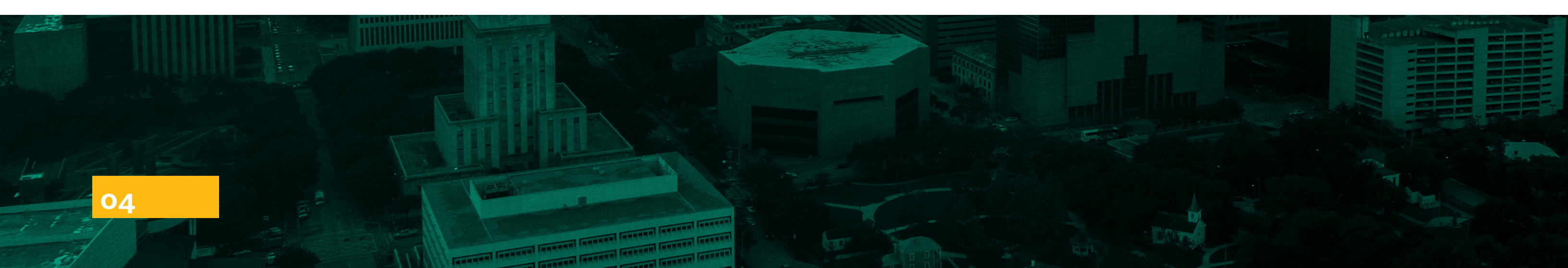


Table 1. Summary of Houston's Climate Impact Assessment[10] Report[4].

Indicator	1971-1990 (Observed)	2051-2070 (lower)	2051-2070 (higher)	2081-2100 (lower)	2081-2100 (higher)
Days per year above 100 °F	1 day (0-8 days)	12 days (0-51 days)	23 days (0-80 days)	14 days (0-53 days)	55 days (5-122 days)
Nights per year above 80 °F	<1 night (0-3 nights)	20 nights (1-73 nights)	50 nights (7-110 nights)	30 nights (1-78 nights)	95 nights (32-143 nights)
Temperature of the hottest day	99 °F (95-103 °F)	104 °F (98-112 °F)	106 °F (98-115 °F)	104 °F (98-113 °F)	109 °F (102-118 °F)
Length of the longest heatwave	2.5 days (1-5 days)	15 days (2-48 days)	27 days (3-79 days)	19 days (4-53 days)	47 days (8-111 days)
First day of summer	June 13th (May 29th-Jul 1st)	May 22nd (Apr 22nd-Jun 19th)	May 14th (Apr 5th-Jun 17th)	May 19th (Apr 16th-Jun 13th)	May 1st (Mar 17th-Jun 2nd)
Last day of summer	Sept 18th (Sept 3rd-Oct 7th)	Oct 7th (Sept 14th-Nov 3rd)	Oct 13th (Sept 18th-Nov 14th)	Oct 9th (Sept 9th-Nov 9th)	Oct 26th (Sept 30th-Dec 2nd)
Length of summer	97 days (70-119 days)	137 days (97-177 days)	152 days (107-206 days)	144 days (105-189 days)	177 days (137-240 days)
March to November cooling degree-days (CCDs)	3050 CDDs (2475-3575 CCDs)	3925 CDDs (2875-4950 CCDs)	4300 CDDs (3250-5600 CCDs)	4075 CDDs (3125-5175 CCDs)	4975 CDDs (3400-6300 CCDs)
Annual heating degree-days (HDDs)	1350 HDDs (1000-1975 HDDs)	950 HDDs (550-1400 HDDs)	825 HDDs (375-1450 HDDs)	900 HDDs (450-1450 HDDs)	600 HDDs (200-1150 HDDs)
Total annual precipitation[1]	51 inches (27-83 inches)	50 inches (18-92 inches)	49 inches (21-106 inches)	50 inches (19-92 inches)	48 inches (15-105 inches)
Annual number of dry days	266 days (251-289 days)	271 days (221-311 days)	273 days (225-311 days)	270 days (227-309 days)	277 days (233-316 days)
Average wettest 3-day precipitation event[2]	6.4 inches (2.1-12.4 inches)	8.6 inches (2.5-26.8 inches)	8.6 inches (2.7-34.2 inches)	8.6 inches (2.8-25.2 inches)	9 inches (2.8-32.1 inches)
Total 20-year precipitation events above 4 inches [3]	19 events (0-100 events)	22 events (0-88 events)	21 events (0-112 events)	23 events (0-92 events)	23 events (0-100 events)

industry's response to the energy transition and efforts to address the impacts of climate change will shape Houston's future.

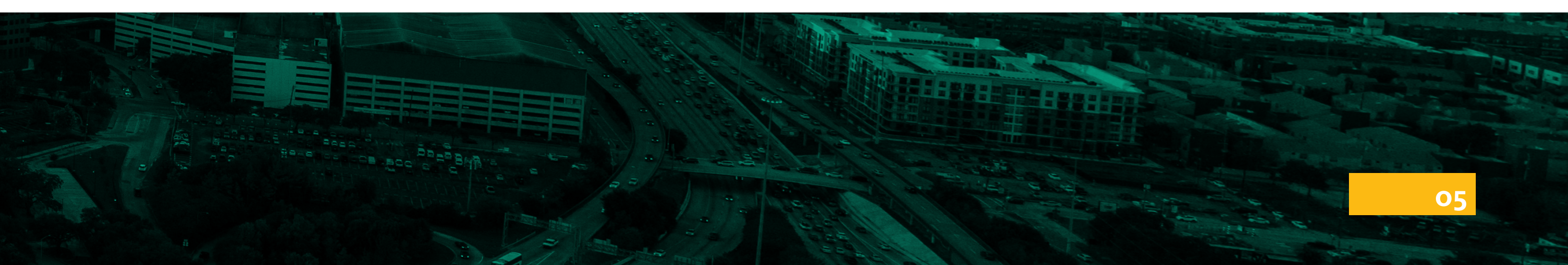
The next section discusses the factors shaping the global and Texas energy markets and net-zero efforts, especially on the supply side, to highlight the varied global and regional forces that will shape Houston's energy economy, infrastructure, and city-wide decarbonization strategies.

This is followed by a discussion of the sectoral implications of these factors, how the findings of the IPCC's Sixth Assessment Report could impact the city's climate action and resilience efforts, and the implications for the city's socioeconomically vulnerable populations and the energy workforce.

FACTORS SHAPING THE GLOBAL AND TEXAS ENERGY MARKETS

The energy transition aims to tackle three key elements: providing safe, reliable, and affordable energy to a growing population, acknowledging that our existing energy system will evolve substantially but many parts of the current system are the underpinnings of the future energy system, and reducing energy-related emissions is imperative.

This has raised strategic questions for the energy industry, especially for oil and gas companies. At the same time, the industry's resources and skills will play a critical role in helping many decarbonization and clean energy technologies to reach market readiness and maturity.



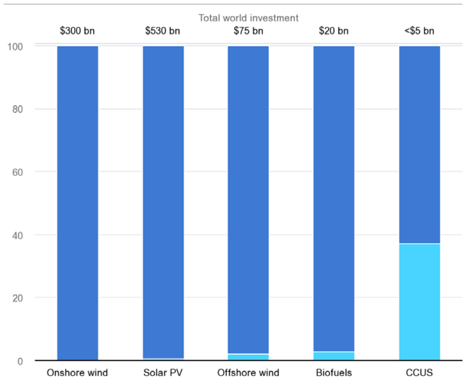


Figure 3. Share of global capital investment in selected low-carbon technologies (2015-2018) where light blue indicates the investments by oil and gas companies and dark blue indicates the investment by other companies. Source: IEA[12]

Global oil and gas investment is set to rise by 20% this year with growth driven by increasing oil prices, geopolitics, market volatility, and large-scale projects in Brazil, Guyana, West Africa, and Australia. Among these, the Russia-Ukraine war had an outsized and anomalous impact on global energy markets.

The U.S. witnessed a 65% year-over-year increase in WTI crude oil prices in the second quarter of 2022[13], and gasoline prices saw a 43% increase over the same time frame. Investment in shale is set to increase by 35%, with the most in the Permian basin, followed by investment in deepwater offshore drilling, which is set to increase by 30%. Most of this increased production can be attributed to private companies that more than doubled their collective rig count in the basin between January 2021 and April 2022 .

In contrast, public companies responded differently to these economically favorable conditions and high oil prices. While production by public companies is still challenged by labor shortages and supply chain issues that have impacted the industry throughout the COVID-19 pandemic, these companies utilized the economic gains from this period to further their net-zero strategies and accelerate investment in decarbonization solutions.

This summer, natural gas prices increased to levels unseen since 2008. In the U.S., the spike was driven by high demand for cooling as temperatures soared through many states. The U.S. EIA expects the Henry Hub price to average $7.54/MMBtu in the second half of 2022 and then fall to an average of $5.10/MMBtu in 2023 as natural gas production increases[8]. The U.S. also stepped up its natural gas exports to Europe to mitigate shortages induced by the Russia-Ukraine war.

Between January and April 2022, the U.S. exported 75% of its natural gas to Europe, which is more than double the share of exports to Europe last year. The increase in U.S. LNG exports was driven by additional export capacity at Sabine Pass and Calcasieu Pass that came online this year. The U.S Bureau of Labor Statistics reported that from June 2021 to June 2022, prices for imported natural gas increased by 165.5%, which is the largest year-over-year increase since March 2003[16].

In the short-term, increased U.S. LNG exports to Europe and 14 new federally approved LNG export facilities, export capacity to Europe is expected to double by 2026, which will support additional jobs[7]. In the long-term, sustained job growth will be dependent on how companies respond to proposed U.S. methane regulations and the European demand for cleaner natural gas. These regulations, outlined in the U.S. Methane Emissions Reduction Plan, are expected to mitigate 41 million tons of methane emissions between 2023 and 2035. The regulations include guidelines for monitoring programs for new and existing well sites and compressor stations, a zero-emissions standard for new and existing pneumatic controllers, standards to eliminate venting of associated gas, and capture and sale of gas where sales lines are available, and proposed performance standards for storage tanks, pneumatic pumps, and compressors[18].

In August, federal regulators from the U.S. EPA undertook flyovers in the Permian Basin to investigate super-emitters of methane in the region, address noncompliance with the methane regulations stated above, and refer violators to the Department of Justice. After these surveys, the Texas Oil and Gas Association released a statement stating that efforts to identify and lower methane emissions have been successful due to investments in technologies like handheld optical imaging cameras, drones, flyovers, leak detection and repair techniques, the replacement of pneumatic valves with zero-emission pneumatic controllers, and that the Permian

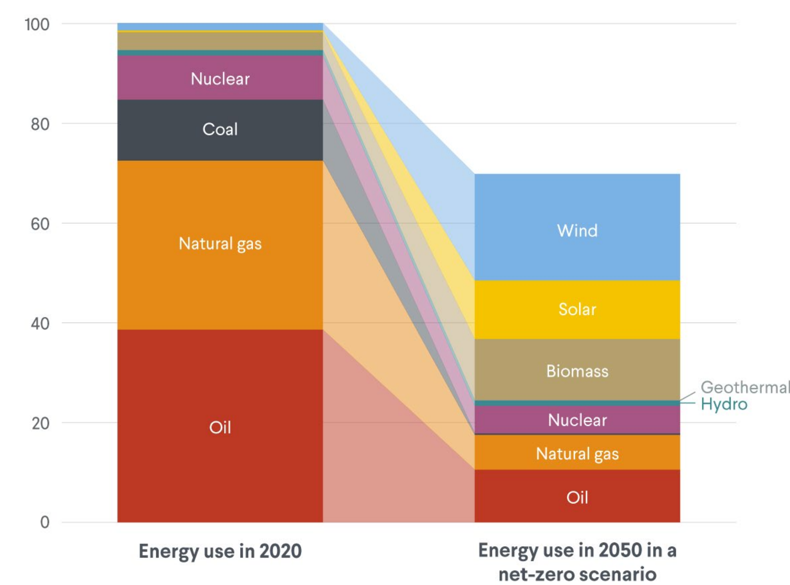
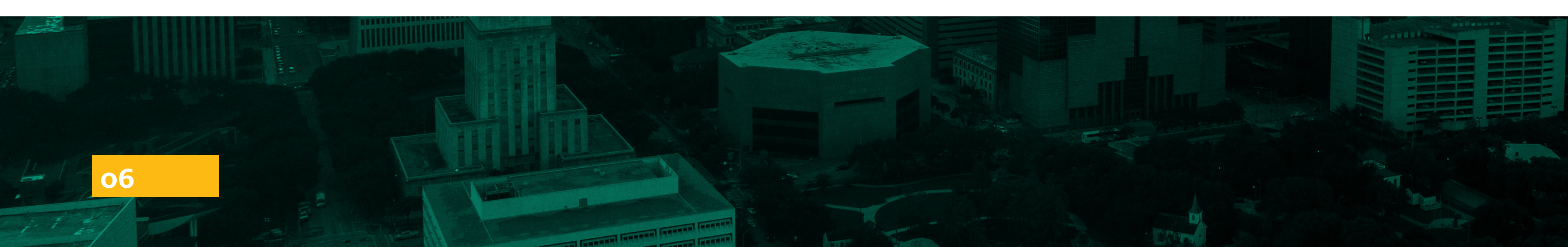


Figure 4. Primary energy use in exajoules in the US, 2020 and a net-zero scenario for 2050. Source: IEA[8]



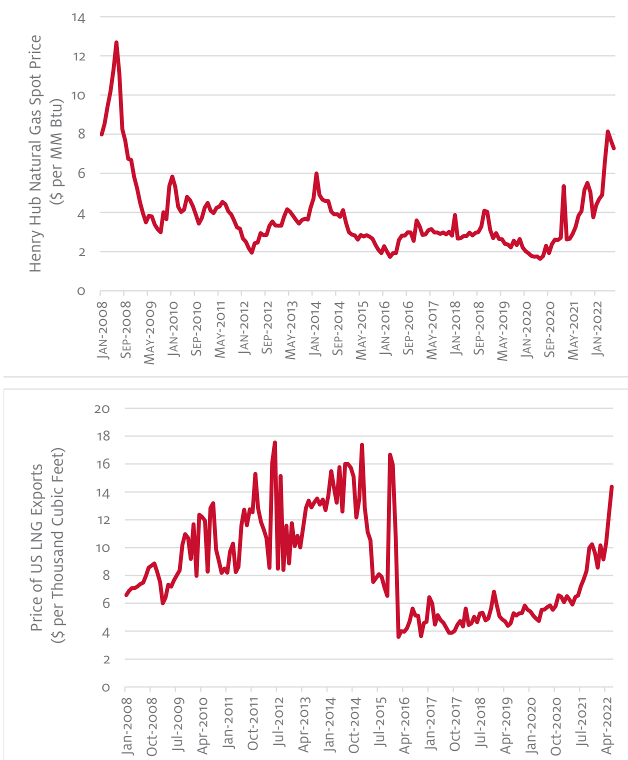


Figure 5. Henry Hub natural gas spot price in $ per MMBtu (top panel) and the price of U.S. LNG exports in $ per thousand cubic feet (bottom panel). Source: EIA[17]

Basin has been able to reduce its methane intensity by about 70% since 2011 due to these measures[19].

In addition to the EPA's regulations, the Texas General Land Office recommends the following methane mitigation practices[20]:

- Use Leak Detection and Repair (LDAR) programs by identifying equipment leaks from oil and gas production equipment, such as tank battery thief hatches and vent valves, pipe connections, compressor seals, flanges, compression fittings, and mechanical seals.
- Aerial flyover surveys using technology that can identify large air emission sources so operators can quickly detect and mitigate the most problematic emissions sites.
- Use of best emission management practices, typically including the utilization of Vapor Recovery Units, Vapor Recovery Towers, Thermal Oxidizers, and Flare Stacks to manage emissions from oil, condensate, and produced water storage tanks.
- Purchase of infrared cameras to improve emission inspection efforts across all assets on State Lands, regardless of facility age or production volumes.
- Recommended membership in The Environmental Partnership, an operator-driven organization committed to voluntary emission reduction programs, transparent reporting, sharing of best practices, learnings, and new technologies.
- Recompleting or plugging abandoned or marginally productive wells.
- Participation in the U.S. Department of Energy's study to quantify methane emissions from marginal wells.

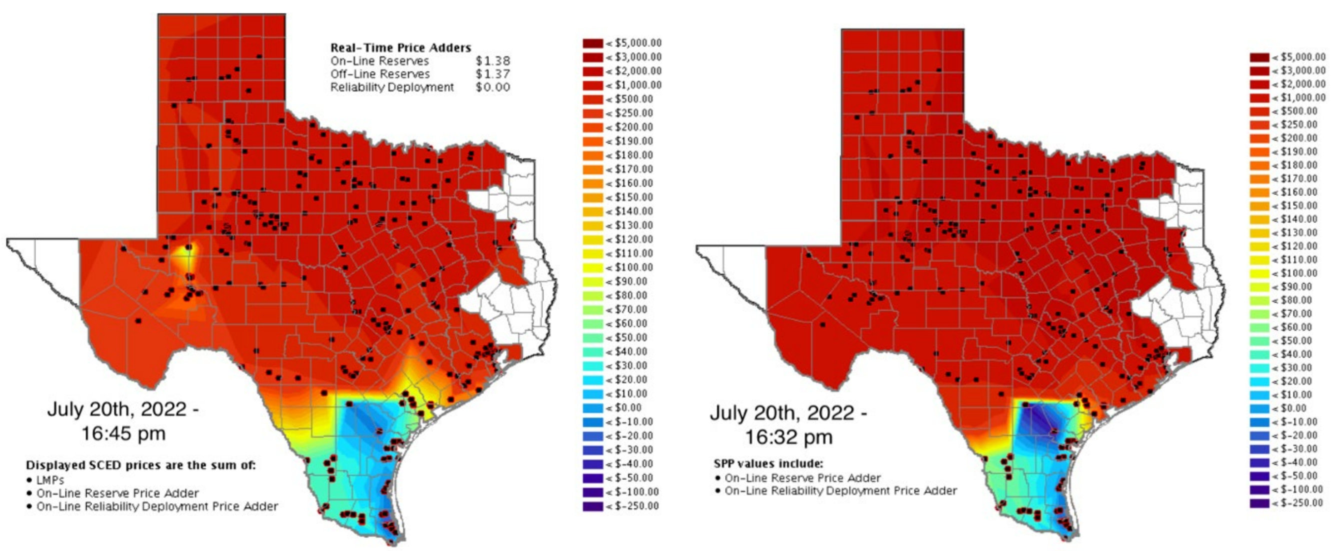
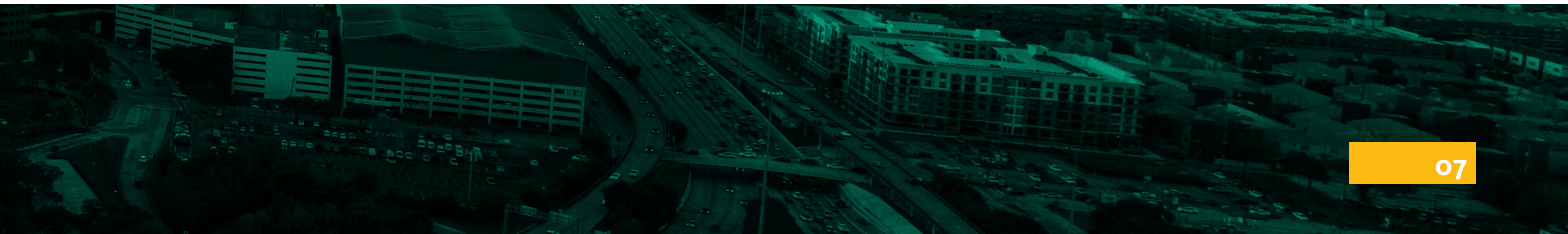


Figure 6. Real-time locational pricing – Security Constrained Economic Dispatch[8] (SCED) prices (left) and Real-time Market-Settlement Point prices (right) for July 20th, 2022. Source: ERCOT[22]



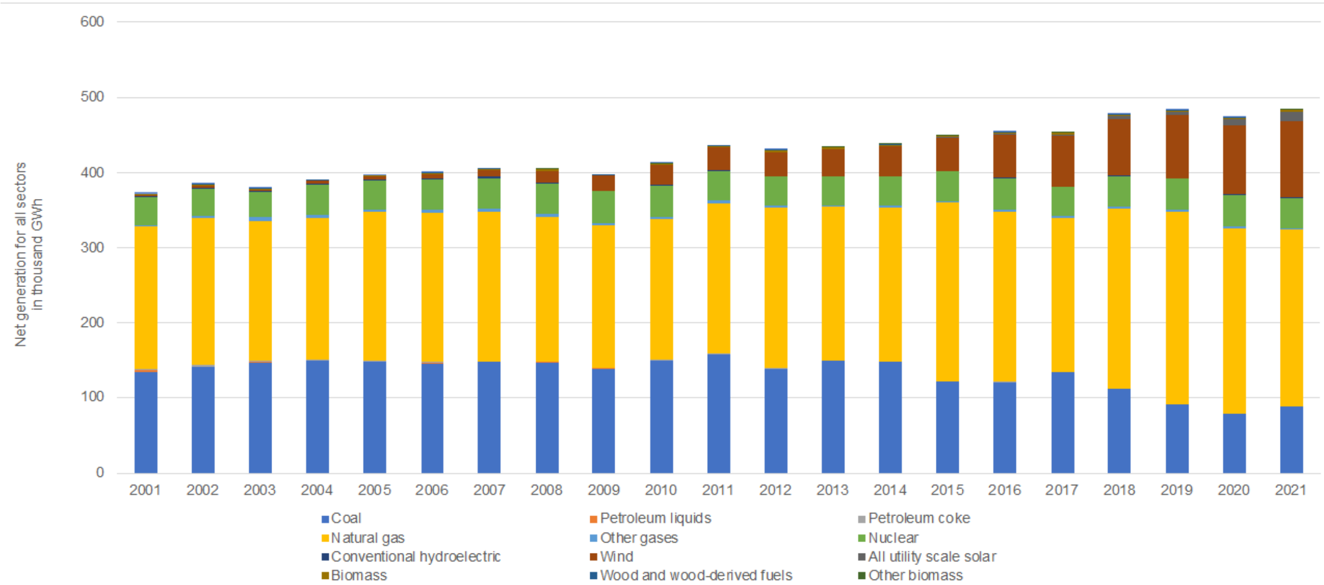


Figure 7a. Annual energy generation, by fuel type and net generation, in Texas between 2001-2021 in thousand GWh. Source: EIA[26]

• Ensure that flare stacks are properly employed, maintained, and operational, including so that gas production that is sent to a flare stack (i) is authorized to be flared (rather than transported from the facility by pipeline), and (ii) is flared rather than merely vented.

Additionally, as part of the federal administration's plan to mitigate methane emissions, the Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA) is expected to finalize the following regulations:

• Gas Gathering Pipeline Safety Rule. This rule proposes to impose new requirements on more than 400,000 additional miles of previously unregulated pipelines, including new safety requirements for a substantial portion of these lines.

• Automatic Shut-off Valve Rule. This rule, which is also known as the Valve Installation and Minimum Rupture Detection Standards rule, proposes to require operators of newly constructed and entirely replaced large diameter pipelines to install rupture mitigation valves or alternative equivalent technologies, and will establish minimum performance standards for operation,

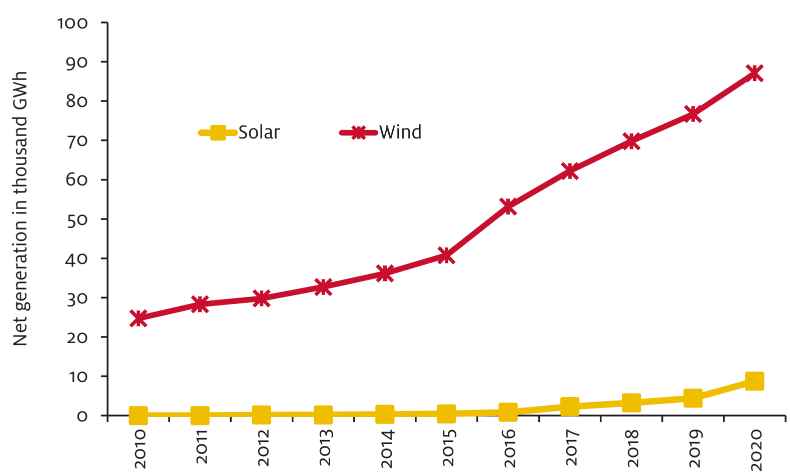


Figure 7b. Annual energy generation from wind and solar (utility-scale) based electricity generation in Texas, 2001-2020 in thousand GWh. Source: EIA[26]

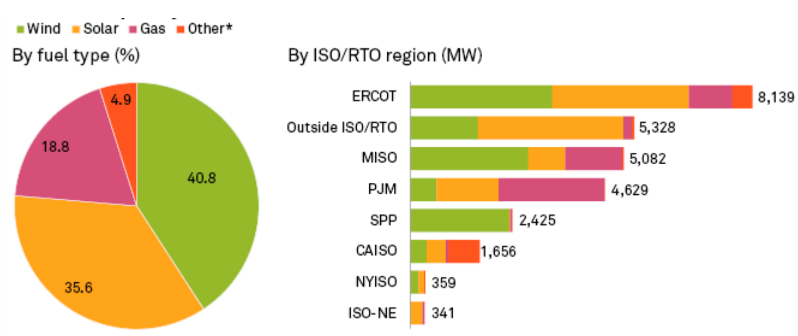
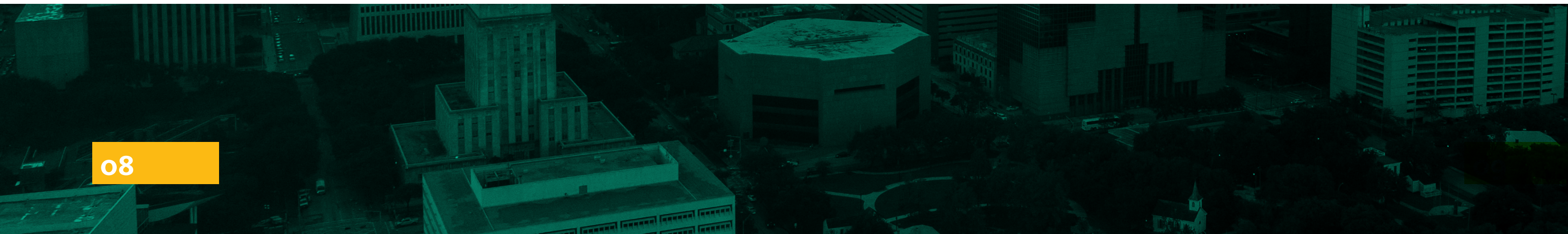


Figure 7c. Capacity additions to the U.S. grid in 2021 - national cumulative capacity addition (left) and by regions (right). Source: S&P Global[27]



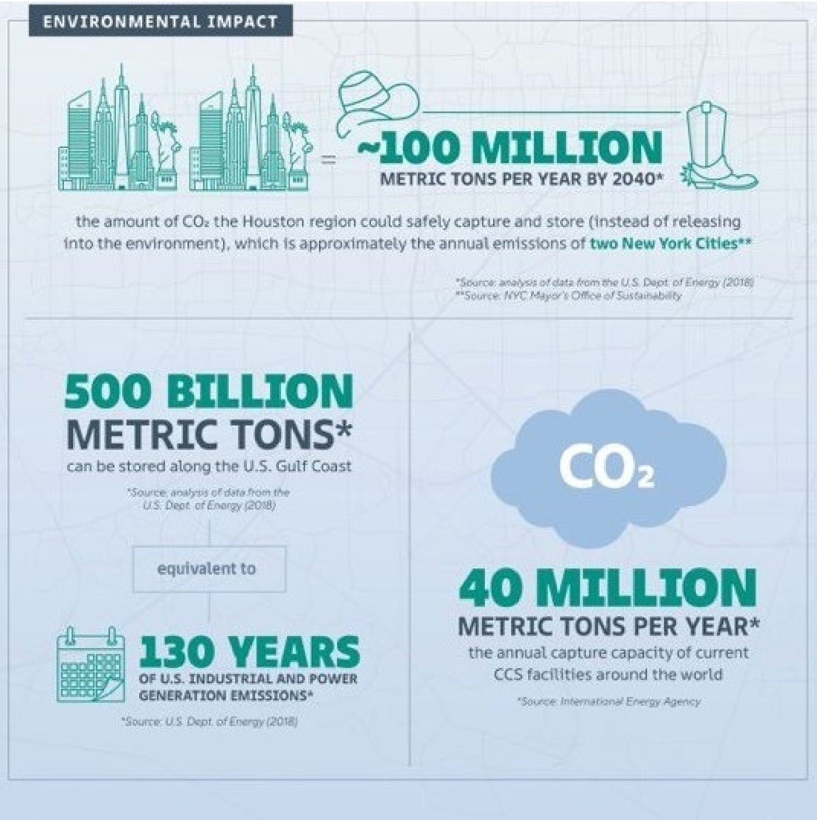


Figure 8. The Environmental Impact of the Houston CCS Alliance's efforts in the region. Source: Houston CCS Alliance[29]

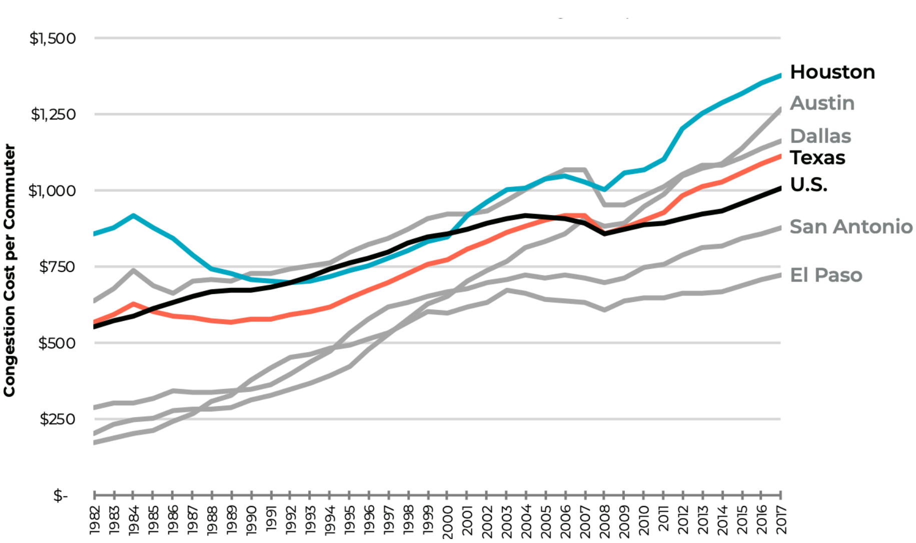


Figure 9. Annual estimates of wasted dollars per commuter from congestion. Source: Texas2036.org[33]

rupture mitigation maintenance, inspection, and risk analysis.

• Gas Transmission Pipelines Safety Rule. This rule proposes to reduce the frequency of leaks and ruptures on more than 300,000 miles of gas transmission lines by addressing integrity management provisions, management of change processes, gas transmission pipeline corrosion control requirements, requirements for inspections following extreme events, strengthened integrity management assessments, and repair criteria for heavily populated/high consequence areas.

OUTLOOK FOR THE TEXAS ELECTRICITY GRID

Texas' electricity mix must change significantly for deep decarbonization. Figure 7a and 7b highlight how the state's electricity mix changed between 2010 and 2020, and capacity addition in the U.S. and across ISO/RTO regions by fuel type in 2021[21,22]. Key takeaways include:

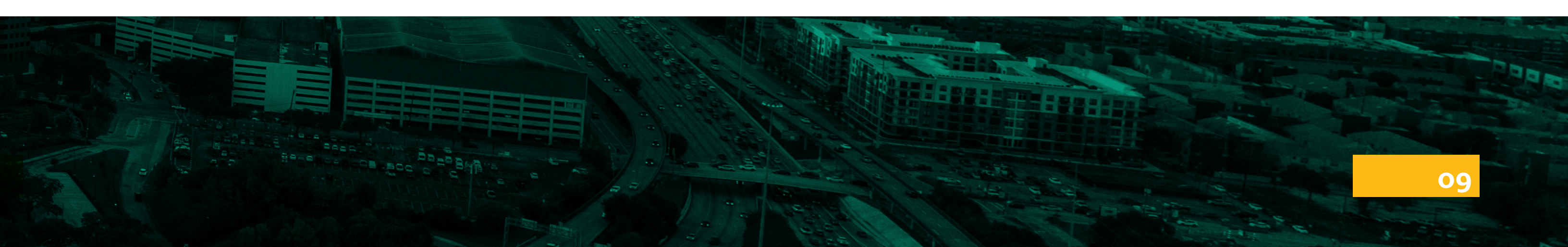
• The grid's reliance on natural gas for electricity production is expected to decrease, while renewable electricity energy will increase.

• Coal and natural gas constitute more than 60% of the fuel mix for current electricity generation.

• Texas already produces more electricity from wind energy and natural gas than any other U.S. state. Of the 8,139 MW of new capacity additions in 2021, wind, solar, and natural gas contributed 42%, 40%, and 13%, respectively.

While the Texas grid will add more renewable capacity, the challenges of grid management and frequent extreme weather events posing reliability concerns are likely to persist in the absence of new investments in infrastructure and grid resilience. Grid congestion and electricity market distortions (Figure 6) were significant in the summer of 2022 and require immediate attention.

Figure 6 presents snapshots from July 20th, 2022 when a spike in the electricity demand



resulted in prices that ranged between \$180 to \$5000 per MWh for much of the state[22]. The left panel maps the real-time SCED prices which is ERCOT's real-time pricing mechanism to ensure the least cost dispatch of online resources, at 4:45 pm.

The right panel maps the real-time settlement price points at 4:32 pm. The color-coded energy maps indicate that the regions in red were those that had high demand and high prices, while the blue and purple regions had low demand and low prices[22]. Grid congestion resulted in an inability to transmit electricity to where it was needed even though there were regions in the south of the state that had negative wholesale electricity prices.

Texas added more than 200 MW of energy storage at the Gambit Battery Storage and New Fork Battery Storage projects, representing 38% of the new energy storage capacity in the U.S. in 2021. In 2022, Texas' largest battery project to date, the 260 MW DeCordova Energy Storage Facility in Granbury, came online. ERCOT's Seasonal Assessment of Resource Adequacy for Summer 2022 stated that 2,035 MW of operational battery storage resources, including 283 MW of planned additions, were expected in the state over the summer months .

However, this represents only about 10% of ERCOT's reserve margin for the summer of 2022 (22.8%). ERCOT did not include battery storage in its reserve margin calculation as it does not provide sustained capacity. Most energy storage projects are suitable for short-term events that require a quick response to keep voltage and frequency stable and can meet one to two hours of peak demand when renewable energy is scarce . As more renewable energy comes online and energy demand increases, the state will need to invest more in grid-scale storage and its grid infrastructure.

Specifically for the Greater Houston region, with a growing population, electricity demand is expected to increase by at least

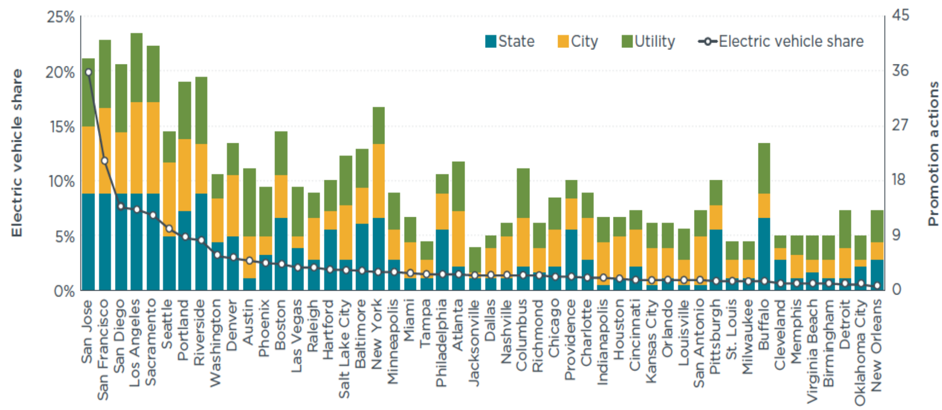


Figure 10. EVs as a share of new vehicles sold and promotion actions in the 50 most populous U.S. metropolitan areas as of 2020. Source: C40KnowledgeHub[35]

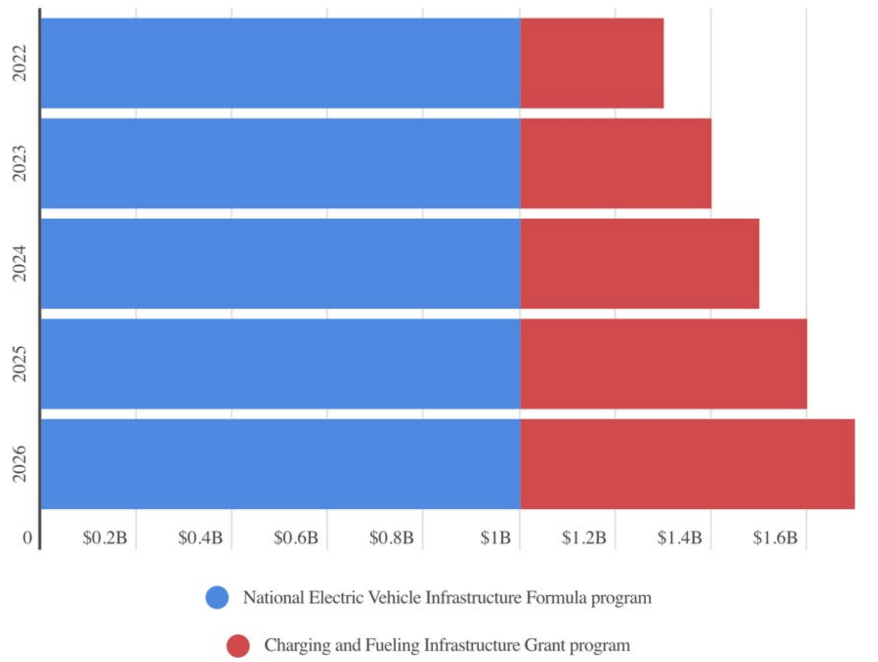
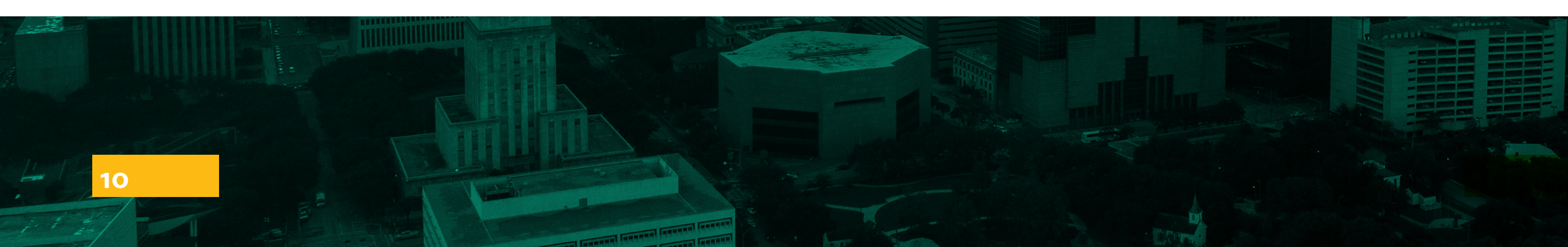


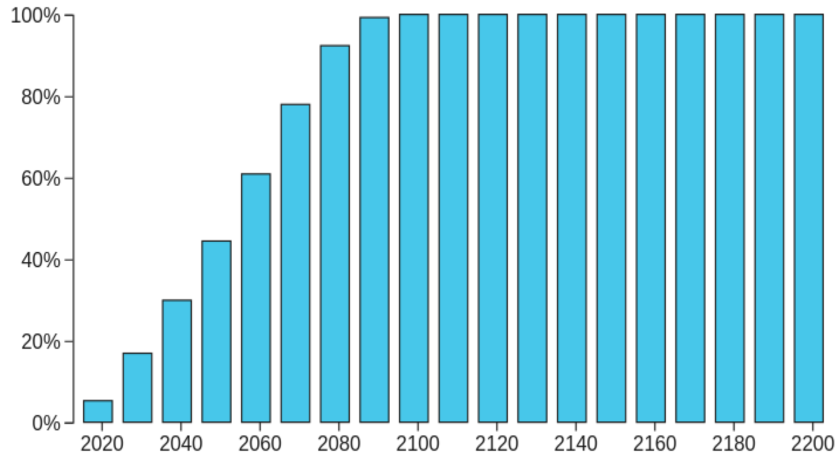
Figure 11. IIJA funding for EV infrastructure by fiscal year, 2022-2026. Source: U.S. Department of Transportation[37]

50% by 2035, and double by 2050. The City of Houston leads municipal consumption of low-carbon energy in the U.S. with all its energy demand being met by renewable energy sources. The city receives ~1,034 GWh of renewable electricity annually from a Texas-based utility-scale solar facility to power its municipal operations. This has allowed the City of Houston to reduce its effective direct carbon emissions from municipal operations by 85% since 2005 .

IMPLICATIONS FOR HOUSTON'S CLIMATE ACTION PLAN

Houston is one of the top GHG emitters amongst U.S. cities at about 35 million tons CO_2 eq per year and per capita emissions of 14.3 tons CO_2 eq. With the launch of the CAP[5] in 2020, the city focused its efforts to reduce emissions by 40% by 2030 and become carbon neutral by 2050. The plan prioritizes the following focus areas to respond to the impacts of climate change:





*At "Galveston Pier 21 water level station, 53 miles from Houston

Figure 12. Multi-year risk of at least one flood above 7 feet, compared to 2016 baseline. Source: National Oceanic and Atmospheric Administration[47], Climate Risk Finder[48]

- Energy Transition
- Optimization in Buildings
- Transportation
- Waste Management

The energy transition and decarbonization efforts in the CAP[5] are directed at Carbon capture, utilization, and storage (CCUS), hydrogen development, and increasing the share of renewable energy. For the optimization of buildings, the city's plan includes improvements in efficiency for residential, commercial, and industrial operations. Transportation includes multiple and equitable transportation options, along with transitioning to EVs and reducing vehicle miles traveled (VMTs). Lastly, the city aims to reduce waste to landfills and material consumption, and increase recycling, up-cycling, and composting.

Given the current energy mix and the city's strategic advantages, the following key enablers in the CAP can help Houston lead the energy transition. Opportunities, challenges, and enablers for the transportation sector are discussed in the following section.

Carbon Capture, Utilization, and Storage (CCUS)

• Various efforts to develop and deliver CCUS at scale have been pioneered in the Houston area. Most notable is the Petra Nova carbon capture facility which captured 1.4 MMt of CO_2 annually. Pioneering efforts to demonstrate and scale up an oxy-combustion-based Allam cycle power generation by Net Power is continuing to redefine the CCUS marketplace. The University of Houston has partnered with the Southern States Energy Board and the U.S. Department of Energy to develop pathways to accelerate the commercialization of CCUS. As part of the Houston CCS Alliance, 14 companies in the area are evaluating the potential for Houston and the Houston Ship Channel to serve as a national CCUS hub that would capture and safely sequester 50 MMt CO_2 eq by 2030 and double that capacity by 2040[28].

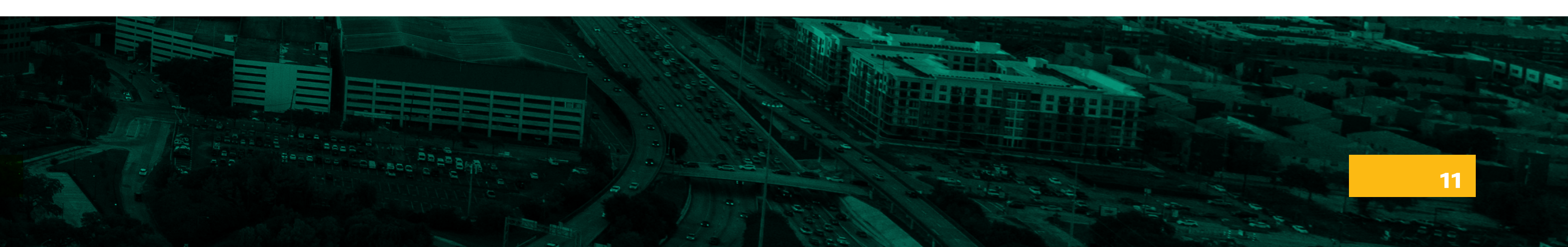
In May 2022, Chevron, Talos Energy, and Carbonvert announced an expanded joint venture to develop the Bayou Bend CCS offshore carbon capture and sequestration hub originally held by Talos and Carbonvert. In 2021, the Bayou Bend CCS was the winning bidder for the carbon storage lease, located in state waters offshore Beaumont and Port Arthur, Texas. The Bayou Bend CCS project site encompasses over 40,000 gross acres and could potentially sequester 225 to 275 MMt of CO_2. Houston's unmatched infrastructure and workforce experience, in addition to the proximity to onshore and offshore geological storage potential of nearly 500 Gt CO_2 can help accelerate the deployment of large-scale CCUS facilities.

Hydrogen

• Houston is also uniquely positioned for large-scale hydrogen production and transportation through the region's existing refining-related steam methane reforming (SMR) and autothermal reforming (ATR) plants and pipeline infrastructure of 900 miles of hydrogen pipelines that represent 56% of the U.S. and 32% of global capacity[30]. Currently, 48 plants in the region produce 3.4 MMt of hydrogen, predominantly through SMR and ATR based on natural gas. This represents 34% of annual U.S. hydrogen production. The region also hosts the largest global caverns for hydrogen storage[31]. Chevron Phillips' Clemens Terminal has stored hydrogen since 1980 and has a usable hydrogen capacity of 2,520 tons[26]. The stored gas has an energy capacity of 892 GWh and is directly connected to the Old Ocean refinery. Air Liquide's Gulf Coast cavern also stores hydrogen and aims to expand its hydrogen network by 90 miles to southeast Texas[25]. Extensive port infrastructure can also help the region export hydrogen and compete with major global producers. Estimates suggest that the demand for hydrogen in Texas could grow to 11 MMt locally and 10 MMt for exports by 2050, which could globally abate 220 MMt of CO_2, add 180,000 new jobs, and $100 billion in economic value[32].

Increasing the share of renewable energy and energy storage

• The city's $70 million investment in the Sunnyside Solar Farm is expected to mitigate 60,000 tCO_2 each year. The project will be the largest urban solar farm with a capacity of 70 MW, including 2



MW community solar, and will be hosted on 240 acres of land that formerly served as a landfill[33]. The project advances the city's environmental justice efforts by bringing investments to a historically under-served and under-resourced community and plans to add 150MWh of battery storage to boost grid reliability in the community.

Optimization in buildings

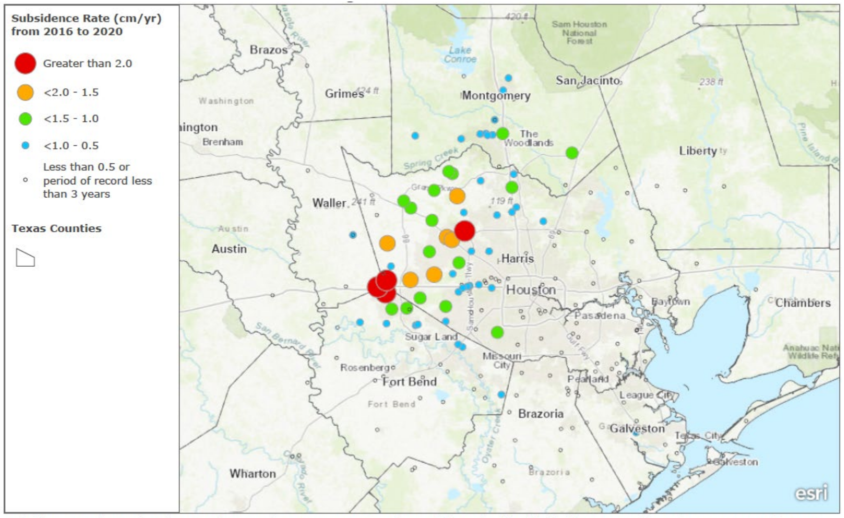
• Houston has consistently ranked high amongst the U.S. cities reducing energy use in commercial and multifamily buildings. As of 2021, Houston was 7th amongst metro areas with the most ENERGY STAR-certified buildings and 5th for LEED-certified buildings[34]. The 195 ENERGY STAR certified buildings in the Houston-Sugarland-Woodlands area have helped save more than $41 million and abated nearly 250,000 tCO_2.

Regulating methane emissions in the region

• A trillion cubic feet of natural gas has been flared in the Permian Basin since 2013. If all wells performed at the industry best practice of 0.4% flaring intensity, operators would eliminate 90% of all flaring in the Permian Basin[35]. This can result in increased volumes for exports and market opportunities that demand cleaner natural gas. Additionally, if Texas adopts a 98% gas capture policy, 84% of routine flaring volumes and 40% of total flared volumes in the Permian Basin could be mitigated at no cost and add $400 million of wellhead value by 2025[31].

A series of studies that evaluated methane emissions in the U.S. natural gas supply chain found that the U.S. EPA had potentially underestimated and underreported emissions by ~60%[36]. Of these, midstream operations, or the gathering, processing, transportation, and storage of natural gas, account for nearly 40% of total preventable methane emissions in the supply chain[37].

An assessment of opportunities to reduce midstream methane emissions found that improving infrastructure integrity and implementing improved real-time emissions monitoring resulted in increased revenue for midstream as well as upstream operators[36]. Sectoral attribution of methane plumes in the Permian Basin indicated that 50% of detected



Subsidence rates in Harris and surrounding counties, Texas, USA. Annual rate of change in ellipsoidal height measured in centimeters per year from GPS data collected from 2016 to 2020. Period of record (POR) plots for each station are included in the link provided in the station popup.

Figure 13a. Subsidence rates in Houston and surrounding areas, 2016-2020. Source: Harris-Galveston Subsidence District[49]

emissions resulted from production activities, 38% from gathering and boosting, and 12% from processing, which was a 20% relative shift from upstream to midstream compared to other large U.S. oil and gas basins[38].

The implications of improving the integrity of the natural gas value chain and minimizing methane flaring and direct venting of natural gas are substantial to the Houston area; including for lower-carbon intensity electricity generation, LNG exports, and as a cheap and reliable feedstock for the chemicals and petrochemical industries in the Greater Houston area.

The Greater Houston area, for instance, is responsible for nearly half of the nation's base

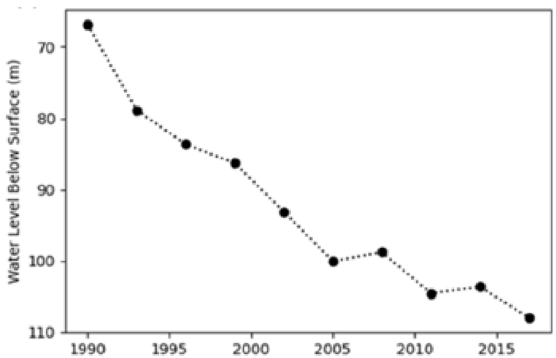
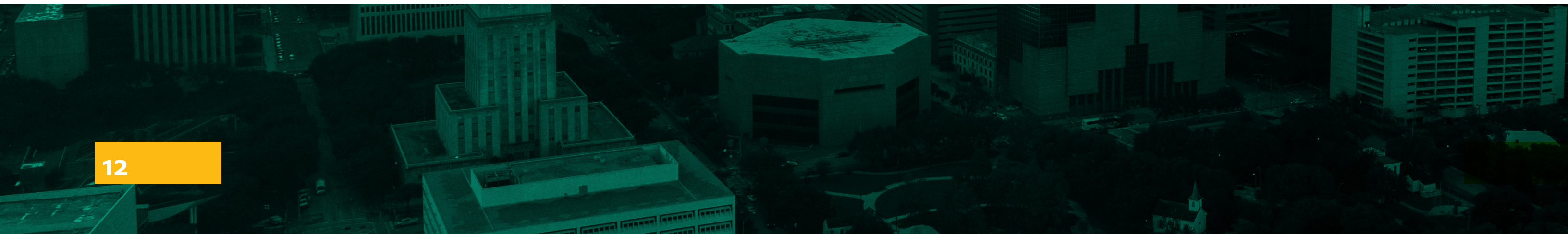


Figure 13b. The average groundwater level in Katy, 1990-2020. Source: Khan et al.[41]

petrochemical capacity[39]. To improve the industry's transparency for methane emissions measurement, reporting and mitigation Pioneer, ConocoPhillips and Devon Energy Group joined the Oil and Gas Methane Partnership 2.0 Initiative, a joint effort by the United Nations Environment Program and the Climate and Clean Air Coalition, in August 2022 .

MITIGATING TRANSPORTATION EMISSIONS

The GHG emissions from the transportation sector in Houston have increased by 130% since 1990, and the sector currently accounts for 47% of the City of Houston's emissions. Currently, the city is ranked 98 out of 100 U.S. cities on the Transportation Climate Index[32]. To



address emissions from the transportation sector and increase multiple and equitable transportation options, Houston's CAP[5] aims to:

- Increase share of EVs to 30% of new vehicle sales by 2030
- Convert non-emergency light-duty municipal fleet to 100% EVs by 2030
- Reduce per capita VMT by 20% by 2050
- Have zero traffic-related fatalities and serious injuries by 2030
- Construct 500 miles of high-comfort bike lanes by 2025

In addition to emissions reduction, better air quality, and improved public health, achieving these targets will also result in cost savings. Data from 2017 (Figure 9) suggests that Houston commuters spent the most time in traffic at the highest cost of any Texas city with 75 hours stuck in traffic at a cost of $1,376 per year, while the state average was 54 hours in traffic at a cost of $981 per year.

In Houston, EVs currently account for nearly 3% of all vehicle registrations and have more than doubled since 2020. While the CAP aims to have EVs account for 30% of new car sales by 2035, Evolve Houston[43], a public-private partnership between the City of Houston, the University of Houston, and three corporate partners[9] that grew out of the CAP, is aiming for a more aggressive target of 50% of new car sales by 2030.

Figure 10 compares Houston against other most populous U.S. metropolitan areas on the metrics of the share of EVs sold as a share of new vehicles and actions undertaken by state and local governments and utilities to promote greater EV penetration in these markets[44].

The 2022 Inflation Reduction Act (IRA) includes provisions to accelerate the purchase of electric vehicles, wherein a tax credit covers either the vehicle's incremental cost or 30% of the electric vehicle's purchase price—whichever is less.

The credit will provide up to $7,500 for vehicles lighter than Class 1-3 vehicles and up to $40,000 for Class 4-8. The Infrastructure Investment and Jobs Act (IIJA) includes funding for electric vehicle infrastructure through $5 billion for the National Electric Vehicle Infrastructure Formula that would *support the installation of publicly accessible charging infrastructure and establish an interconnected network for data collection, access, and reliability,* and $2.5 billion in Charging and Fueling Infrastructure Grants to *provide competitive grants to states, local governments,*

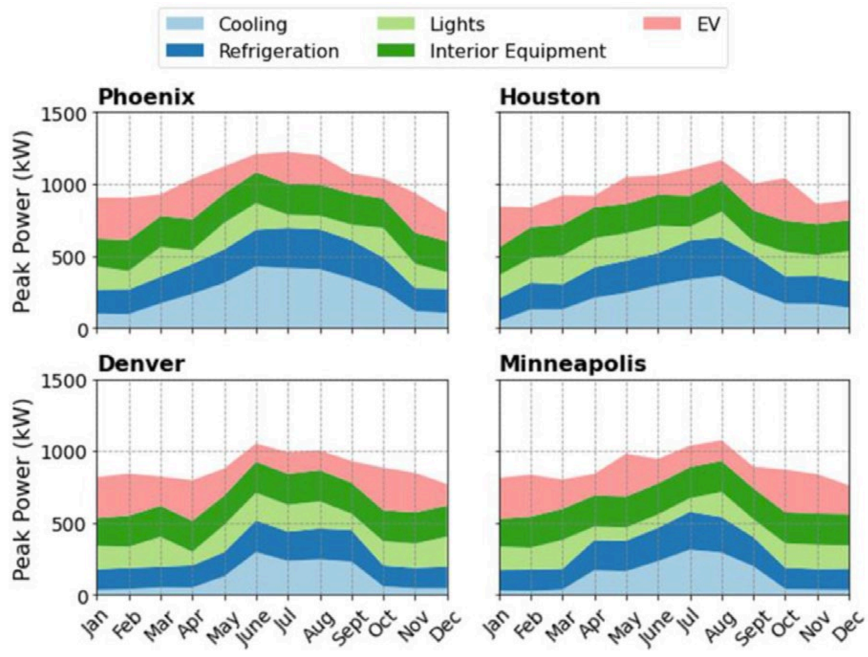


Figure 14. The component breakdown for monthly peak power demand at 1-minute intervals for two-port, low-utilization, 150-kW-per-port station for a retail building simulated in four cities: Phoenix, Houston, Denver, and Minneapolis. Source: Gilleran et al.[42]

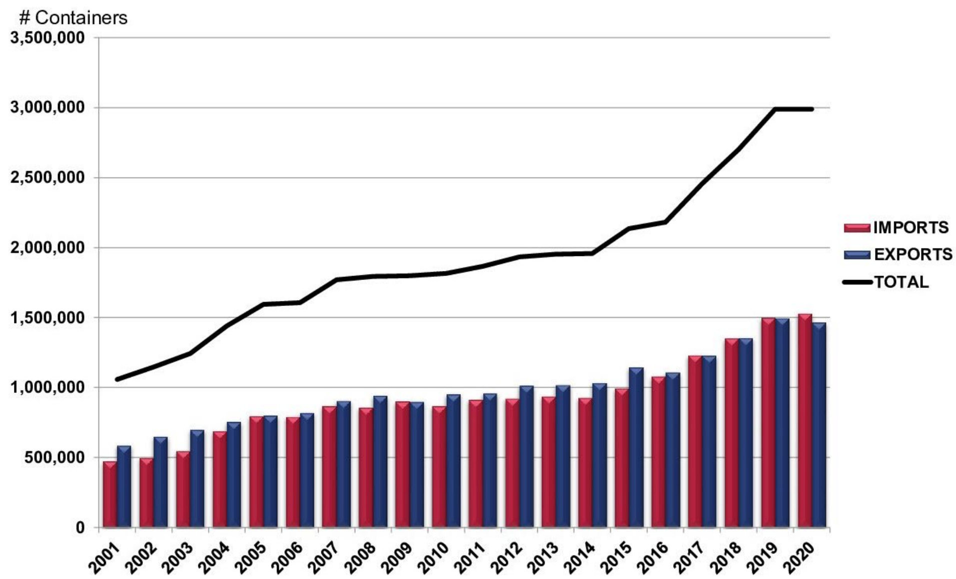
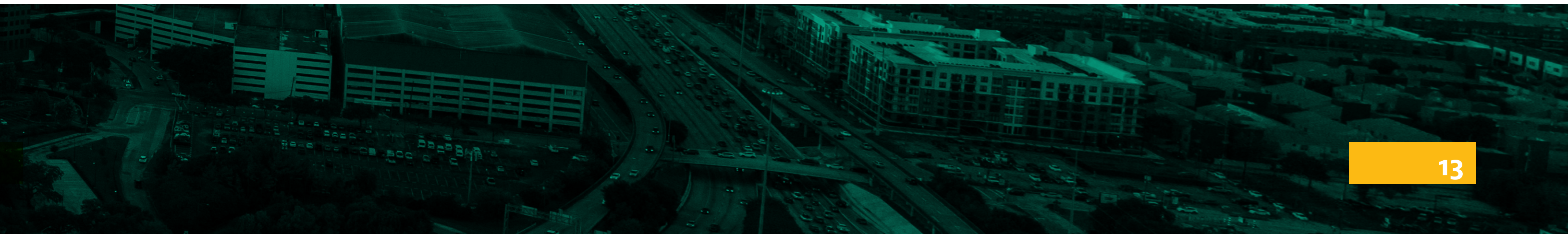


Figure 15. Growth of containers in the Houston Ship Channel, values include empty containers. Source: Lloyd's List[58]



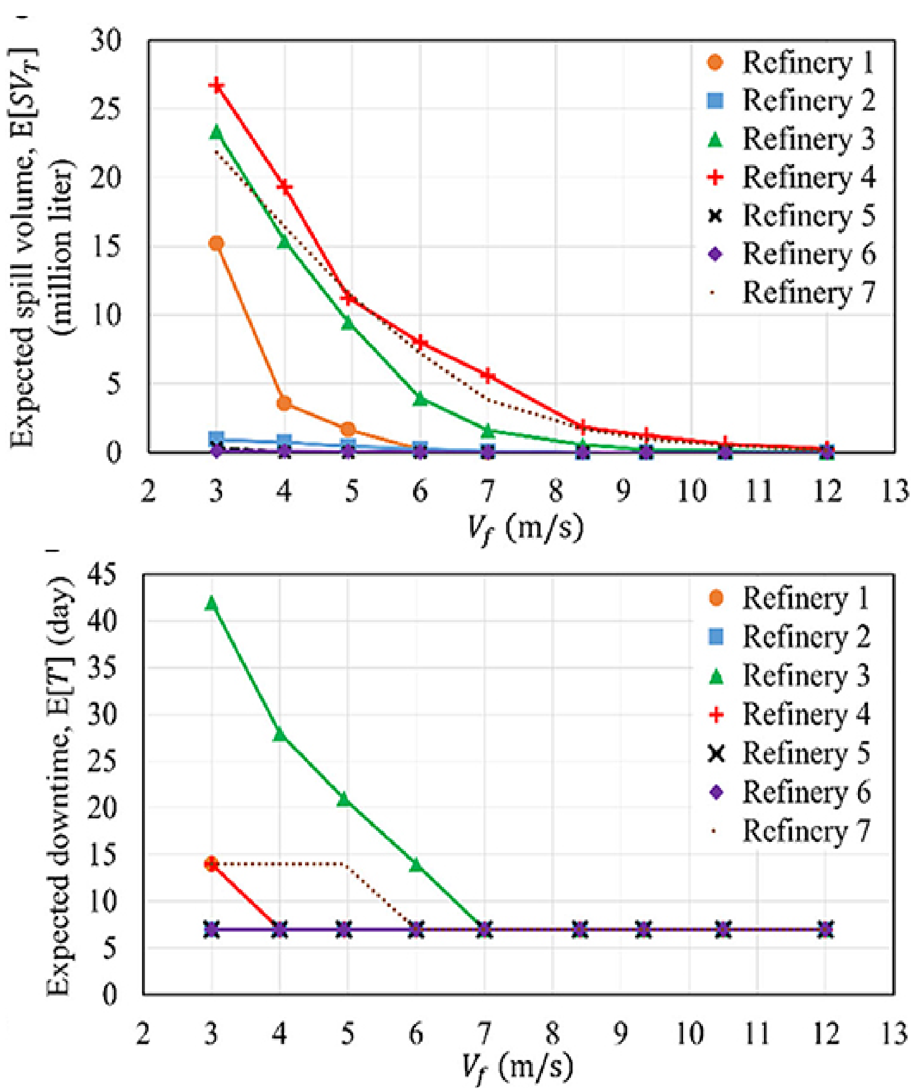


Figure 16. Expected spill volume and downtime as a function of hurricane forward speed (Vf) at 7 refineries and aboveground storage in the Houston Ship Channel, assuming a 100-year still water flood elevation scenario and no sea level rise. Source: Sichani et al. 2020.

metropolitan planning organizations, and other public-sector entities to support the installation of publicly accessible charging infrastructure—or stations for alternative fuels such as hydrogen or natural gas. IIJA requires at least 50% of these funds to *be designated for a community grant program prioritizing rural and low- and moderate-income communities with a low ratio of private parking spaces*[45].

The Texas Department of Transportation has updated its electric vehicle infrastructure plan to support the federal priorities.

Meanwhile, the Greater Houston area had 467 charging stations and 1,200 total charging ports in September 2021.
At that time the existing number of public charging stations was adequate to meet the city's demand, but Evolve Houston anticipates that the need for more EV charging stations will rise exponentially after 2030.

Regional efforts and funding for EV infrastructure totaled $10 million at the end of 2021, but to support the goal of EVs reaching 50% of new vehicle sales by 2030, more than $400 million in funding will be required[46].

LOCAL IMPACTS AND CLIMATE RESILIENCE

Rising Sea levels, Increased Precipitation, and Flooding

Houston is projected to experience 5.3 feet of sea level rise by 2100, compared to a 1993 baseline and independent of the impact of land subsidence[8].

Over this period, precipitation will average 9 inches for the wettest 3-days[8]. The combined effect of sea-level increase and increased precipitation will result in an exponential growth in flooding risks.

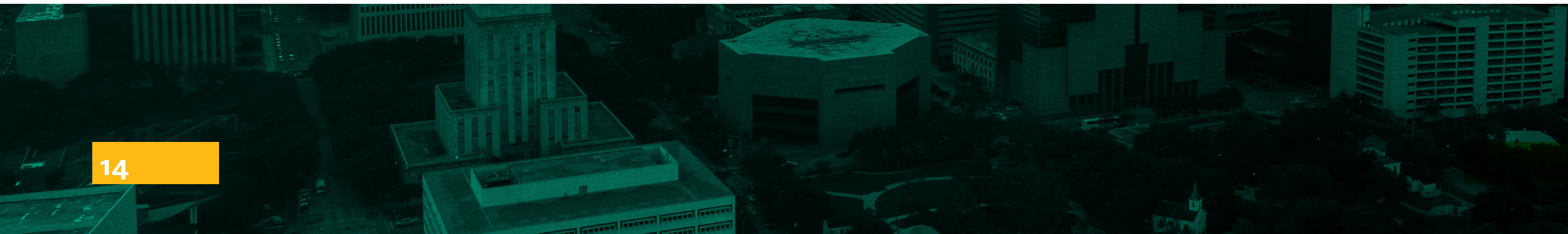
Currently, about a quarter of the homes in the Houston area face a significant flood risk. Increased precipitation by 2100 means that the annual risk of at least one flood exceeding 7 feet in the region will increase by15% by 2030, 45% by 2050, and 100% by 2100[10, 47, 48].

Water, Land, and Energy

In 2017, the Drinking Water Operations division of the City of Houston supplied more than 160 billion gallons of drinking through to the region through its 7,500-mile pipeline distribution system[49]. The City of Houston's reliable surface water rights comes from reservoir and run-of-river yield from Lake Houston (100% City of Houston-owned), Lake Livingston (70% City of Houston-owned), Lake Conroe (70% City of Houston-owned), and river flows within the lower Trinity River.

The City of Houston also owns 70% of the proposed off-channel Allens Creek Reservoir project which it plans to use after 2025 to meet the region's water demand[49]. The population in the Greater Houston Area is expected to grow by 1.3% year-over-year from 7.1 million in 2020 to 8.3 million in 2030[8].

As a result, the city is expected to experience a 35% increase in its municipal water demand by 2070 (and a doubling in the demand for housing). The City of Houston's assessment[49] of the impact



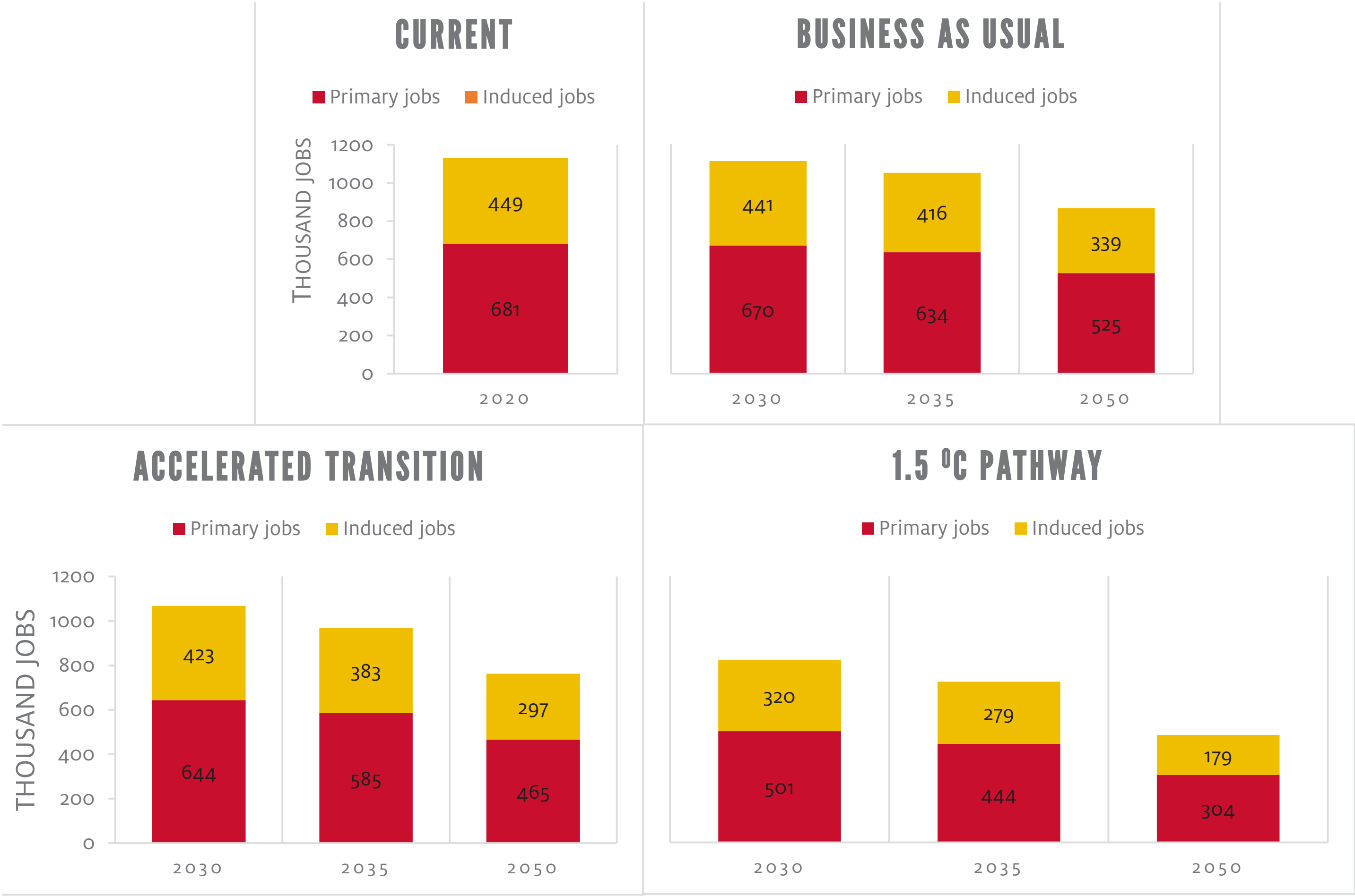


Figure 17a. Direct and indirect energy jobs in Houston, if the city does not lead the energy transition. Data source: Greater Houston Partnership[46]

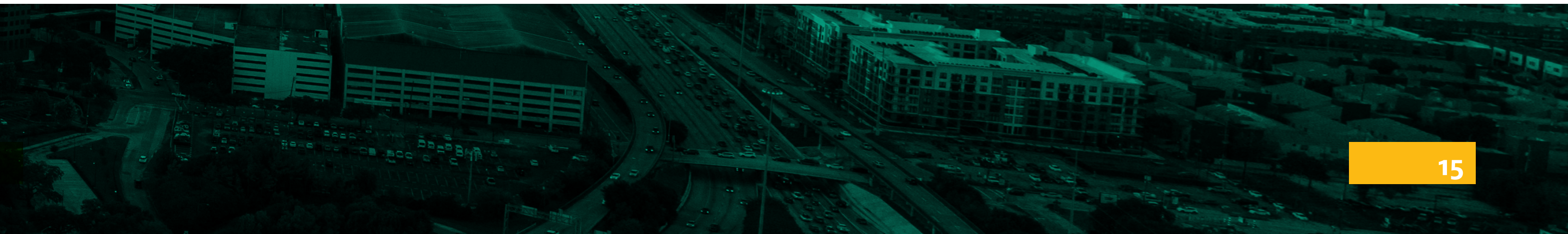
of population growth on the region's freshwater resources asserts that the region has sufficient water supplies for its wholesale and retail customers through 2050.

Currently, the city is experiencing land subsidence at 10 mm/year, with areas north and west of Houston subsiding at rates as high as 27 mm/year[8,50]. These include the areas of Katy and The Woodlands, where the hotspots for low groundwater are expected to be exacerbated, as groundwater pumping increases with a year-on-year population growth of 3.4% and 1.8% respectively[37]. As Figure 13b indicates, the average groundwater level in Katy has been consistently declining, from 66.9 m below the ground surface in 1990 to 108 m in 2020. Moreover, subsidence from prolonged flooding and storms in these areas poses a risk of sediment compaction and flood-induced subsidence[51].

The City of Houston has gradually reduced its dependency on groundwater to mitigate subsidence concerns. About 20% of the current water supply is provided by groundwater resources and the City plans to convert to 100% surface water by 2025 and acquire additional surface water rights to meet the future 50-year water projections, pending approval from the Texas Commission on Environmental Quality (TCEQ)[49].

The increased stress on land resources from groundwater pumping, new constructions, and expansion projects are expected to exacerbate land subsidence. The 2022 outlook for the Houston area Industrial Market highlighted that leasing velocity reached 10 million square feet in the first quarter of the year[53]. Currently, the area has over 18 million square feet under construction and an additional 65 million square feet proposed or in the final planning stage, while the vacancy rate in the first quarter of the year decreased from 8.7% in 2021 to 6.5% in 2022.

The population increase will also result in overall increased demand for energy. For cooling, the energy demand is expected to increase as cooling degree days increase by 1.5 times by 2100[8]. However, this will be accompanied by a decrease in energy demand for heating as heating degree days are expected to reduce by 1.5 times over the same period[8]. A recent study of EV charging stations on the electricity demand for retail buildings in four U.S. cities found that fast charging can make a significant impact on



a site's peak demand and increase monthly peak demand by over 250% in some cases, and the effect was stronger as per-port power levels increase[54]. However, the study found comparatively little effect on the building's monthly electricity use.

Implications for Houston's Energy Infrastructure

The Gulf Coast region hosts over 45% of the U.S. petrochemical facilities[55]. Currently, the Houston region supports 49% of the U.S. Polypropylene production capacity, 40% for Polyethylene, and 50% for Polyvinyl chloride.

The global petrochemical market is expected to grow by 5% year-over-year through 2030 or by $275 billion[56]. Resultantly, the sector will account for over a third of the growth in oil demand by 2030, and nearly half of the increased demand by 2050, ahead of trucks, aviation, and shipping. The sector would also need an additional 56 bcm of natural gas by 2030 to meet the growing demand.

The increase is fueled by the growing demand for consumer staples and household goods, which saw the largest increase in demand in 2020. U.S. and European consumers drove much of this demand by consuming 20 times more plastic and 10 times more fertilizers than developing countries.

Climate Risks for the Houston Ship Channel and Energy Infrastructure

The Houston Ship Channel, one of the U.S.' largest ports in terms of waterborne tonnage, is among the facilities most vulnerable to climate and extreme weather risks. Operational disruptions from extreme weather events in the past have caused economic losses of more than $300 million per day[57].

Similarly, for petrochemical facilities in the region, 35-40% of the plant area is expected to be inundated by a 100-year flood[59]. Analyses based on projected flood depths and damage functions have found that high-risk facilities could face significant physical and economic damage of the order of tens of millions of dollars. The damages resulting from the failure of critical equipment and the associated punitive fines could be multiplied manyfold. Over the next decade, the cost of climate risks

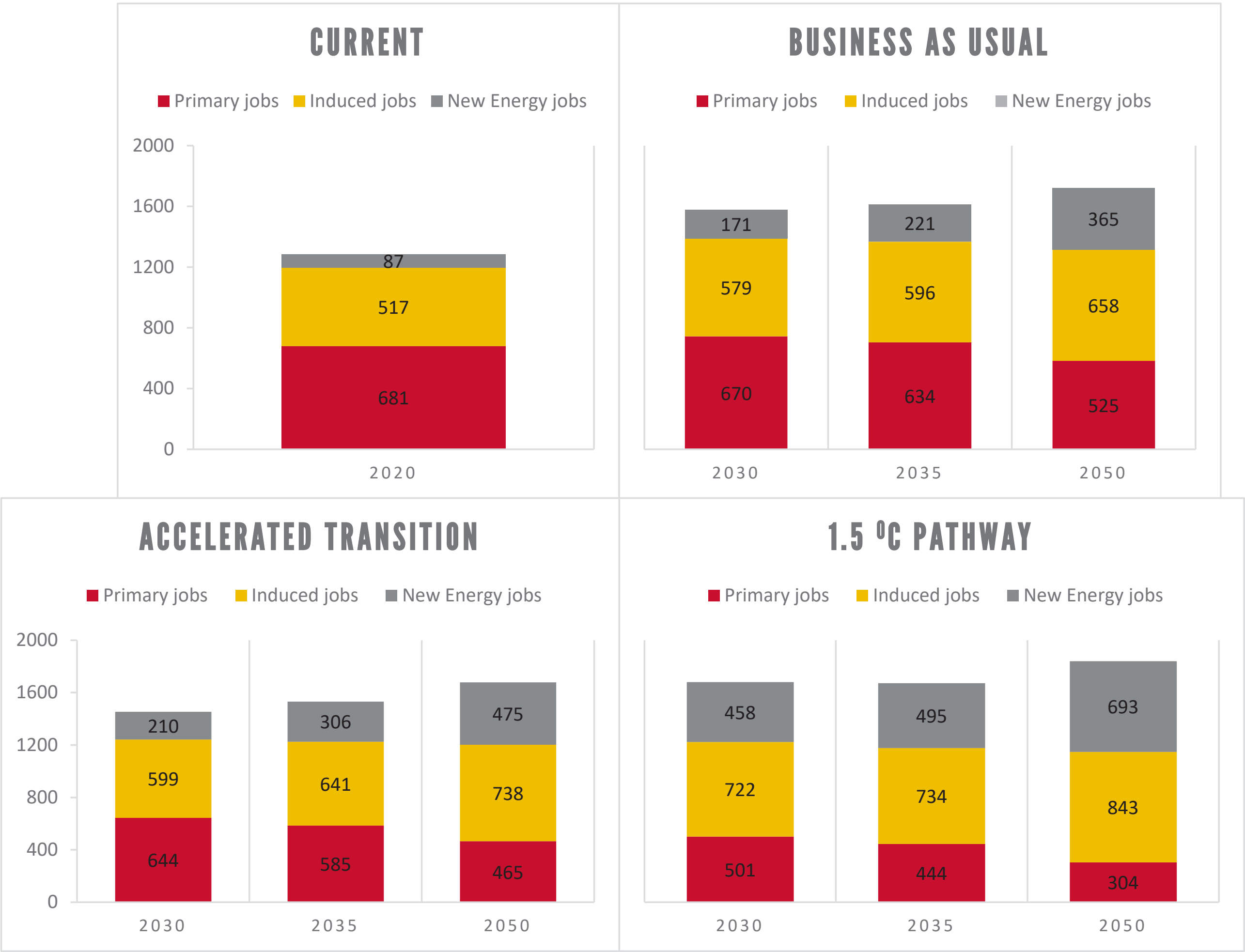
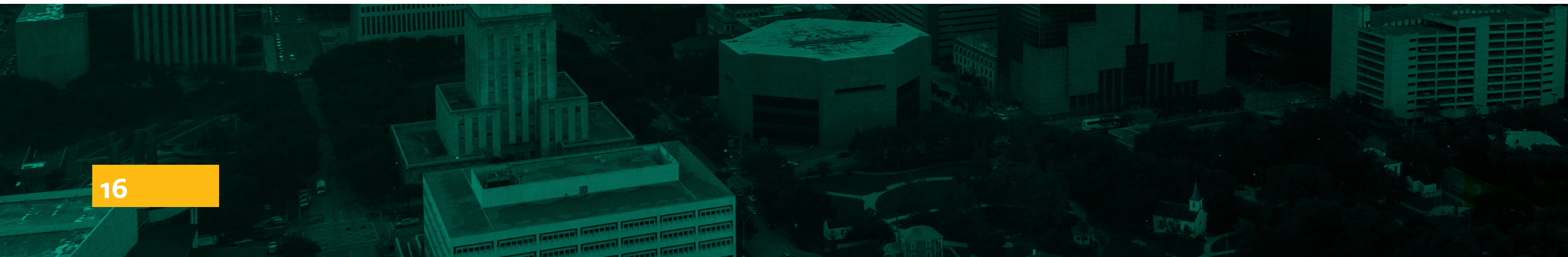


Figure 17b. Gains in direct and indirect energy jobs if Houston leads the energy transition. Data source: Greater Houston Partnership[46]



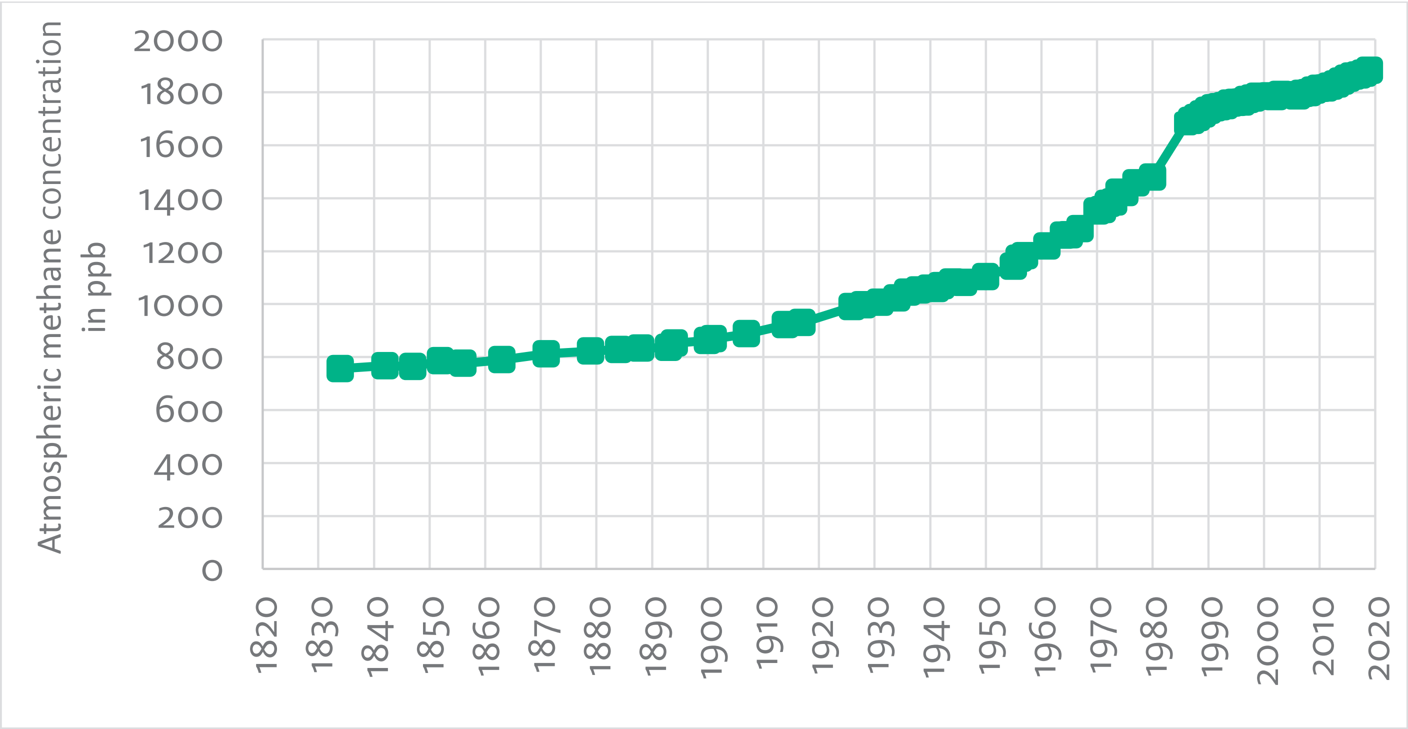


Figure 18a. Global Atmospheric Concentrations of Methane 1834-2019, in ppb. Data source: National Oceanic and Atmospheric Administration[65]

to the Houston Ship Channel and petrochemical facilities in the Gulf Coast region could increase by as much as 800% as the flooded facility area is expected to double, and direct damages will increase by three to eight times[43]. These impacts extend beyond immediate damages, operations and supply chain disruptions, and personnel safety and can have lasting impacts on the neighboring communities and the environment.

An analysis of climate risks in the Ship Channel found that the Dixie Chemical Plant will likely be the most impacted in an extreme weather event. The plant could see an estimated $16M bill after a 100-year flood event by 2030, with average flood depth almost doubling from 2.1 feet to 4.1 feet; damages from a more severe, 500-year flood event would amount to a hefty $300M with catastrophic flood depths of over 7 feet[43]. These damage estimates don't include potential regulatory fines if critical equipment is compromised. To address the lack of risk analysis and management for facilities and to aid emergency preparedness and response, the U.S. EPA recently proposed regulations and guidance for chemical accident prevention at facilities that use certain hazardous substances. It includes guidance to develop a Risk Management Plan which identifies the potential effects of a chemical accident, the steps the facility can take to prevent an accident, and emergency response procedures if an accident occurs, as part of the Clean Air Act[60].

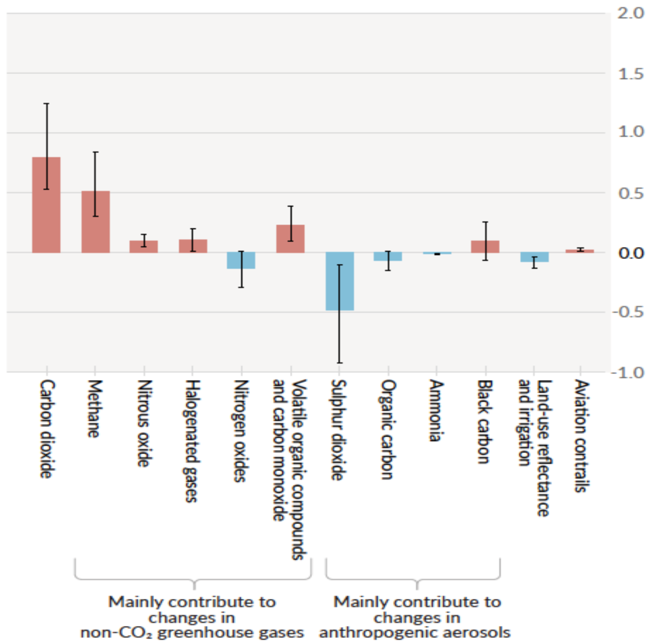


Figure 18b. Assessed contributions to observed warming in 2010–2019 relative to 1850–1900: evidence from radiative forcing studies. Source: IPCC Sixth Assessment Report[7]

An assessment of risks to Houston's energy infrastructure from increased frequency and intensity of hurricanes found that depending on the severity, two general loss profiles exist for refineries. For hurricanes generating low water elevations, total losses in refineries will be dominated by production loss (nearly 70%)[61]. On the other hand, severe hurricanes with high water elevations will result in significant aboveground storage damage and spills. In such cases, the total loss will be dominated by production loss and spill clean-up costs, as indicated in Figure 16.

SOCIOECONOMIC IMPACT

Vulnerability and Inequities in the Recovery from Natural Disasters and Extreme Weather Events

The effects of natural disasters and extreme weather events are not felt equally by all communities. A recent study found that low-income Latino neighborhoods in Harris county experienced disproportionately higher flooding from Hurricane Harvey[62]. UH's Hobby School of Public Affairs' recent assessment of social vulnerability found that households in Texas that were likely to be vulnerable based on their minority status, language, household composition, and disability status were affected the most by natural disasters in the last 20 years[4]. Greater vulnerability to natural disasters and extreme weather events resulted in a higher likelihood of reporting damages. Moreover, over 40% of the households surveyed as part of the assessment reported that they were still recovering from the impacts of Hurricane Harvey (including those who reported that they have mostly recovered)[4].

In July 2022, as part of the Water Resources Development Act, the U.S. Senate approved the construction of the Ike Dike, a proposed coastal barrier in Galveston Bay that would protect against hurricanes and storm surges[63]. The Act sought to approve various federal water, coastal infrastructure, and environmental projects but does not include funding allocation. Ike Dike was conceptualized after the 2008 Hurricane Ike and was proposed as part of the Texas Coastal Project that would include artificial barriers to protect against future hurricanes and rising sea levels. Estimates suggest that the cost of the project ranges from $16-31 billion and would require 15 to 20 years of construction time, which would leave the region vulnerable to natural disasters and extreme weather events in the meantime[45].

Jobs and Workforce Development

Greater labor productivity, technological advancements and increased efficiencies mean that fewer people are needed in existing jobs than before. Between 2014 and 2020, 125,000 upstream and midstream jobs were lost in the Houston region, and even though the industry recovered the jobs lost during the COVID-19 pandemic, these direct jobs and the associated indirect jobs will likely not be fully regained. This 26% reduction in the workforce points to a trend that will continue if Houston stays on a business-as-usual path, losing 270,000 jobs in the hydrocarbon sector by 2050[64].

The city will lose an estimated 370,000 hydrocarbon-related jobs if an accelerated low-carbon transition pathway is pursued elsewhere and Houston continues with business-as-usual, while an estimated 650,000 hydrocarbon-related jobs will be lost if an aggressive 1.5 °C pathway is pursued elsewhere and business-as-usual is maintained in Houston. These scenarios are presented in Figure 17 and are based on projections from the Greater Houston Partnership.

In contrast, if Houston prioritizes climate action and leads the energy transition, the city stands to gain 400,000 jobs with an accelerated low-carbon transition and 560,000 jobs in the 1.5 °C pathway. These would include gains in hydrocarbon-related jobs, and new jobs in the solar, wind, hydrogen, CCUS, biofuels, energy efficiency, energy storage and electric vehicles sectors.

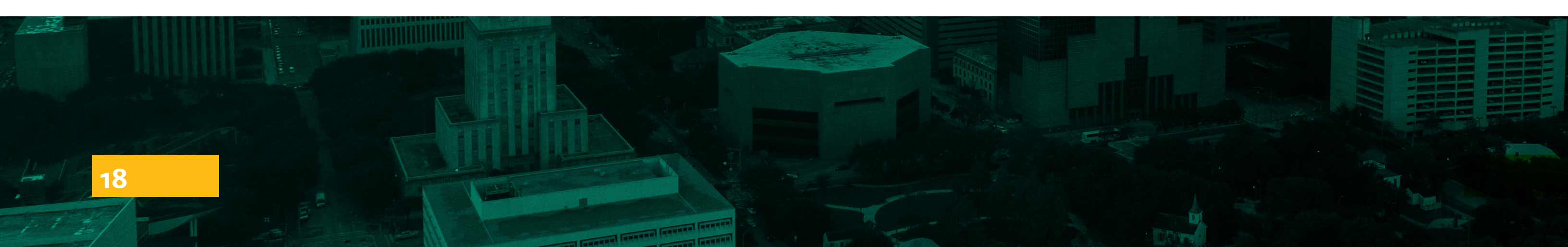
The current workforce has seen many boom-and-bust cycles and has not been insulated against geopolitical shocks, but this transition is unlike any other. Focused reskilling and upskilling opportunities can help identify the knowledge, skills, and experience that will be most valuable for changing and emerging roles and offers a second pathway to bolster energy security and advance the energy transition.

IS METHANE A POTENTIAL DISRUPTOR?

The report also found that relative to a 1750 baseline human-caused radiative forcing of 2.72 W/m2 in 2019 has warmed the climate system[7]. As Figures 18a and 18b suggest, the concentration of methane in the atmosphere has increased by 140% and this is driving about one-third of the warming impact. Despite having a warming impact that is 84 times higher than CO_2, methane has received far less attention than carbon dioxide reduction.

This finding is striking and quantifies the significant climate impacts of methane that must be addressed urgently. This raises concerns for the energy transition strategies of Houston and the US. All current federal, state, and regional plans for electricity generation, petrochemicals, and hydrogen production, as well as for economic and workforce development, energy and national security, and foreign policy are heavily reliant on natural gas as the key transition fuel. Methane's significant warming potential will be a disruptor of the energy transition, and our strategies must rapidly evolve to account for this threat.

While we have a fair understanding of sources of methane emissions, we do not have precise estimates for the different sources of emissions that have caused the recent trend of increasing methane concentrations in the atmosphere since 2007. Four potential explanations have been advanced as the drivers of this trend. They range from increased oil and natural gas production, rising emissions from landfills, growth in livestock farming, and increased microbe activity in wetlands. A recent analysis of ice cores and atmospheric methane has been able to provide strong evidence that microbes, including those in wetlands, livestock farms, and landfills, are responsible for around 85% of the increase in emissions since 2007, while fossil fuel extraction accounts for the remaining 15%[66].



Even though the share of emissions from the energy industry is considerably lower than previously suggested, anthropogenic activities have caused more than 60% of the total methane emissions over the last 15 years. Conversely, effective methane mitigation will result in quick climate gains. In the Permian Basin in Texas, a trillion cubic feet of natural gas has been flared since 2013. Plugging leaks to avoid fugitive methane emissions from wells, pipelines, compressor stations, and processing facilities across 30 super emitter sites in the basin could save the industry $26 million per year[18]. Mitigating fugitive emissions will not only increase the volumes of natural gas available for domestic consumption but also result in increased volumes for exports and provide opportunities to expand into foreign markets that demand cleaner natural gas.

The implications of regulations and securing the value chain will have consequences beyond production and exports. As discussed above, the global petrochemical market is expected to grow by 5% each year through 2030 or by $275 billion, with consumer staples and household goods witnessing the largest increases in demand. Resultantly, petrochemicals will require an additional 56 bcm of gas by 2030[40]. Most of this demand will be in the U.S. Gulf Coast, where the petrochemicals and refining infrastructure is concentrated. Hence, the onus of spurring innovations to mitigate the 110 million tons of CO_2 emissions associated with this increased demand would be on the energy industry in Houston.

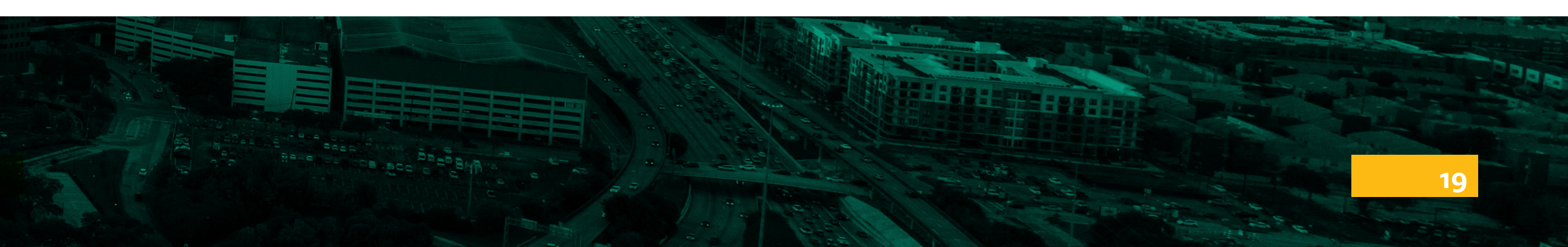
At the same time, curtailing our dependence on natural gas presents a new threat to Houston's strategic and economic advantage. Electricity generation, refining and petrochemicals which includes many consumer staples and household goods, natural gas exports, current and planned expansions to the city's energy infrastructure, and all direct, indirect, and induced jobs are expected to rely heavily on natural gas over the next decade under all energy transition scenarios. If natural gas production is immediately and significantly reduced to account for its climate impact, all four priority areas of the city's CAP will require new strategies.

CONCLUSIONS

The findings from the IPCC's Sixth Assessment report present an opportunity for Houston to expand its climate response and energy transition strategy to include actions against climate threats endemic to the city. This can be achieved by immediately integrating four additional focus areas into Houston's CAP:

- Addressing methane emissions by ensuring the integrity of the natural gas infrastructure and reducing emissions from flaring and venting;
- Strengthening and preparing the energy workforce through relevant upskilling and reskilling;
- Boosting our resilience efforts against flooding, sea-level rise, and land subsidence;
- Site-specific mapping and safeguarding of the city's energy infrastructure facilities.

The city can bolster its efforts to build climate resilience by reassessing its climate risks and mapping how they have evolved since the Climate Assessment that was released in 2020. The findings of that study and the 2022 Houston Climate Impact Assessment 2.0 are based on the 2017-2018 Fourth National Climate Assessment, and climate risks for Houston have likely intensified since then. Updating the risk analysis in the context of the forthcoming Fifth National Climate Assessment will provide an improved understanding of the risks. Additionally, the targets and goals defined in the Climate Action Plan and the Resilient Houston Strategy can benefit from a detailed plan of climate resilience priorities that is neighborhood-specific and integrated across the Houston metropolitan area, the timeline for achieving the outlined goals and key milestones, a description of the city's efforts to allocate funds towards these priorities, and the coordinated efforts required for effective and broad stakeholder engagement.



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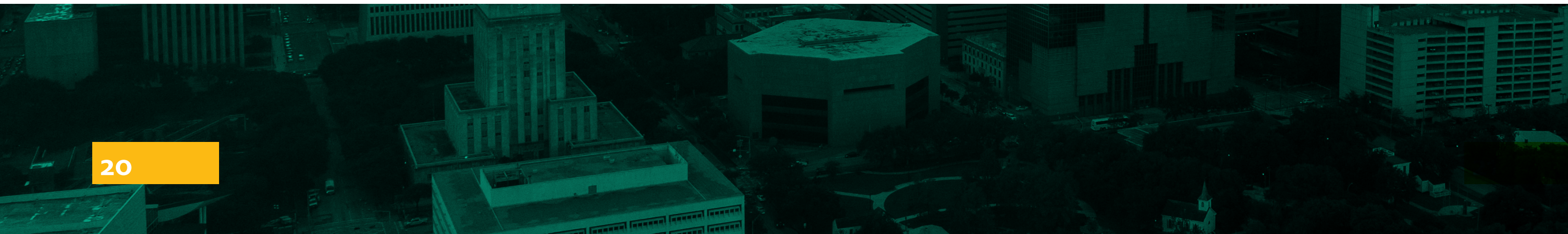

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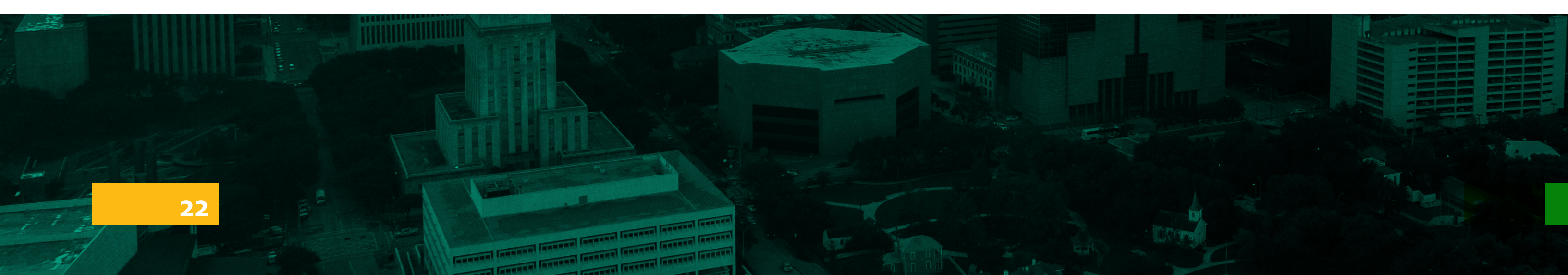

FOOTNOTES

1 – The orange dashed arrow and horizontal orange error bar represent the central estimate and likely range of the time at which 1.5°C is reached if the current rate of warming continues. The grey plume is the likely range of warming responses to a stylized pathway (hypothetical future) in which net CO_2 emissions decline in a straight line from 2020 to reach net zero in 2055 and net non-CO_2 radiative forcing increases to 2030 and then declines. The blue plume is the response to faster CO_2 emissions reductions, reaching net zero in 2040. The purple plume is the response to net CO_2 emissions declining to zero in 2055, with net non-CO_2 forcing remaining constant after 2030. The vertical error bars represent the likely ranges and central terciles of the estimated distribution of warming in 2100 under these three stylized pathways.

2 – Cooling degree days (CDD) are a measure of how hot the temperature was on a given day or during a period of days and designed to quantify the demand for energy needed to cool buildings. CDD is the number of degrees that a day's average temperature is above 650F. The EIA states that a day with a mean temperature of 80°F has 15 CDDs.

3 – Heating degree days (HDD) are a measure of how cold the temperature was on a given day or during a period of days and designed to quantify the demand for energy to heat buildings. HDD is the number of degrees that a day's average temperature is below 650F. A day with a mean temperature of 40°F has 25 HDDs.

4 – Values in parentheses are the lowest to highest value depending on year and/or climate model against the 1971-1990 baseline.

5 – There is significant variability in the climate model projections for total annual precipitation with values for individual years and models ranging between less than 20 inches in some years to more than 100 inches in other years.

6 – The historical simulated values for average wettest 3-day period are slightly higher than observations, likely indicating a small positive bias in future projections.

7 – There is significant variability in the projections for this indicator, with values for individual years and models ranging between zero and 6 events per year with precipitation above four inches.

8 – SCED is the real-time market evaluation of offers to produce a least-cost dispatch of online resources. SCED calculates Locational Marginal Prices (LMPs) using a two-step methodology that applies mitigation to resolve non-competitive constraints.

9 – Evolve Houston's corporate partners include Shell, NRG and CenterPoint Energy.

10 – Compared to a 2016 baseline. The projections are based on a 2018 assessment and IPCC's 2014 RCP scenarios and the risks are likely to have compounded since then.

11 –Through a combination of 1.2 billion gallons per day of surface water rights and 200 million gallons per day (MGD) of available groundwater supplies.

APPENDIX I

List of Abbreviations

1. CAP – Climate Action Plan
2. IPCC – Intergovernmental Panel on Climate Change
3. CDD – Cooling Degree Days
4. HDD – Heating Degree Days
5. WTI – West Texas Intermediate
6. LNG – Liquefied Natural Gas
7. MMBtu – Million British Thermal Unit
8. U.S. EPA – United States Environmental Protection Agency
9. U.S. EIA – United States Energy Information Administration
10. LDAR – Leak Detection and Repair
11. ISO - Independent System Operator
12. RTO - Regional Transmission Organization
13. ERCOT - Electric Reliability Council of Texas
14. CCUS – Carbon Capture, Utilization, and Storage
15. VMTs – Vehicle Miles Traveled
16. SMR – Steam methane reforming
17. LEED - Leadership in Energy and Environmental Design
18. RHS- Resilient Houston Strategy

About UH Energy

UH ENERGY

UH Energy is an umbrella for efforts across the University of Houston to position the university as a strategic partner to the energy industry by producing trained workforce, strategic and technical leadership, research and development for needed innovations and new technologies.

That's why UH is the Energy University.

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