Transforming Chemicals Production in Texas

Methodology and Assumptions

Lever Impact Evaluation Methodology

AI-Driven Predictive Maintenance

1. Scope

- **Technology:** Sensors and AI analytics used to identify emerging failures in pumps, compressors, valves, motors, and instrumentation before they cause a unit upset, shutdown, venting, or flaring.
- **Modeled population:** 52 Texas primary-chemical facilities producing hydrogen, ammonia, methanol, aromatics, or olefins.
- **Event dataset:** 162 maintenance-related TCEQ emissions events reported at nine sampled facilities during 2021–2025.
- **Boundary:** Includes events whose reported cause appeared fully or partly detectable through equipment monitoring; excludes power outages, weather, operator error, and sudden failures without a detectable precursor.
- **Interpretation:** High-end statewide screening estimate, not a prediction of deployment or a guarantee that identified events would be prevented.

2. Methodology

Event identification and emissions

- **Addressability review:** Each event received a weight of 1.0 (detectable), 0.5 (partly detectable), or 0 (not detectable) based on the reported failure mechanism. Weighted addressable events totaled 137.5, or 84.9% of the sample.
- **Time basis:** The 2021–2025 event counts and pollutant totals were divided by five to estimate an average annual rate before statewide scaling, ton reporting, and application of predictive-maintenance effectiveness.
- **State scaling:** For each chemical type, annualized weighted events and emissions per sampled facility were multiplied by the corresponding statewide facility count.
- **Headline case:** A 60% intervention-effectiveness factor and 100% statewide-representativeness factor were applied to 159.7 modeled addressable events/year, yielding 95.8 potentially avoided events/year (approximately 1.8 per facility).
- **Avoided emissions:** Reported emissions were weighted for addressability, annualized, scaled by chemical type, and multiplied by the headline factors. CO_2 was derived for selected flaring events when not reported, using flare-stream composition and combustion assumptions.
- **Headline results:** Approximately 65,000 tons CO_2/year, 27 tons NO_x/year, 137 tons VOC/year, 6 tons benzene/year, and 7 tons 1,3-butadiene/year.

Cost and economic benefits

- **Deployment cost:** Five-year costs include software licensing, connectivity, enterprise support, vendor installation, and internal installation labor. Modeled cost is $0.43–$0.75 million per facility, or $22.4–$39.2 million statewide over five years.
- **Production-benefit method:** Annual avoided events are multiplied by the probability of production interruption, downtime, affected facility production, the unrecoverable share of affected output, and a high-end hourly production-value proxy.
- **Affected versus unrecoverable production:** The assumptions are independent: 40% of full-facility production is affected during an interruption, and 60% of that affected output cannot be made up later. The remaining affected output is assumed recoverable through rescheduling, higher utilization, or inventory management.
- **High-end hourly value:** $400,000 per full-facility hour is used as a high-end screening proxy. Public condition-monitoring guidance notes that production value at major continuous petrochemical facilities can reach hundreds of thousands of dollars per hour and recommends site-specific accounting. After the 40% affected and 60% unrecoverable factors, the model values permanent loss at $96,000 per downtime hour.
- **Modeled benefits:** Avoided lost production value is $6.34 million/facility/year, or $329.5 million statewide/year. Adding the high-end COBRA health benefit of $1.48 million yields a total modeled annual benefit of about $331.0 million.

3. Key Calculations

- **Addressable share =** Σ event addressability weights ÷ total events = 137.5 ÷ 162 = 84.9%.
- **Annualized statewide addressable events =** Σ[(five-year weighted events ÷ five years ÷ sampled facilities) × statewide facilities] = 159.7 events/year.
- **Potentially avoided events =** 159.7 × 60% effectiveness × 100% representativeness = 95.8 events/year.
- **Avoided emissions (tons) =** Σ[(five-year weighted pollutant totals ÷ five years ÷ sampled facilities) × statewide facilities] × effectiveness × representativeness.
- **Five-year deployment cost =** Year 1 cost + 4 × annual year 2–5 cost.
- **Avoided production value/site =** 1.83 events/year × 75% interruption probability × 48 hours × 40% affected production × 60% unrecoverable share × $400,000/full-facility hour = $6.34 million/year.
- **Annual benefit total =** $329.5 million avoided lost production value + $1.48 million monetized health benefits = $331.0 million/year.

4. Key Limitations

- The nine-facility sample is uneven across chemical types and dominated by olefins events; sampled event rates and severities may not represent all 52 facilities.
- Annualization assumes comparable five-year reporting coverage across sampled facilities; incomplete or partial-year reporting would affect annual event and emissions rates.
- Addressability classifications, 60% effectiveness, and 100% representativeness are high-end expert-judgment scenarios, not measured predictive-maintenance performance.
- State scaling assumes similar event frequency and severity within each chemical type and does not adjust for site size, age, existing monitoring, or equipment condition.
- TCEQ event reports vary in completeness; CO_2 for some flaring events is estimated, and preventing an upset may shift some emissions to planned maintenance rather than eliminate them.

- Deployment costs are screening estimates and may omit sensor hardware, control-system integration, cybersecurity, data preparation, training, and added staffing.
- The $400,000/hour value is a high-end order-of-magnitude proxy, not a verified statewide average contribution margin. The affected-production and unrecoverable-output shares are separate screening assumptions, and actual losses depend on product margins, inventories, contractual effects, and production recovery.
- COBRA is a screening model; results do not monetize direct benzene or 1,3-butadiene exposure, worker impacts, acute peaks, safety benefits, repair costs, or reputational effects.

5. Sources

- TCEQ Reports of Air Emissions Events: 2021–2025 event causes and reported pollutant quantities. Source quantities were converted to tons for reporting.
- EPA COBRA Screening Model: monetized PM2.5- and ozone-related health benefits.
- EPA GHG Emission Factors Hub: natural gas combustion CO2 factor used in selected derived calculations.
- EPA AP-42, Section 1.4 - Natural Gas Combustion: combustion-emissions reference.
- US Patent US7838712B2: project proxy for steam-cracker product composition used in selected CO_2 calculations.
- Tractian, How to Build the Board-Level Case for Condition Monitoring in Chemical Operations: supports the high-end order of magnitude for hourly production value at major continuous petrochemical facilities; recommends using site-specific production accounting where available.

Low-Leak Natural Gas Procurement

1. Scope

- **Lever:** Procurement of low-methane-intensity natural gas by target Texas chemical production facilities.
- **Modeled intervention:** Shift modeled upstream production methane intensity from 1.71% to 0.20%.
- **Modeled Texas gas procurement denominator:** 415 million MMBtu/year of natural gas procurement, including fuel and feedstock for target Texas chemical production.
- **Boundary:** Includes upstream methane leakage associated with natural gas supplied to target chemical production; does not model on-site equipment changes at chemical facilities.
- **Health screening boundary:** Uses associated upstream VOC reductions as a proxy COBRA input; does not value methane directly in COBRA.
- **Interpretation:** Full-procurement screening scenario assuming all modeled Texas chemical-sector natural gas procurement transitions to low-leak gas; not an estimate of achievable near-term adoption or physically delivered certified gas.

2. Methodology

Emissions

- **Demand denominator:** Start with annual natural gas procurement for target Texas chemical production, including fuel and feedstock.
- **Methane represented by purchased gas:** Convert gas procurement from MMBtu to methane mass using 1,010 Btu/scf methane heat content and 19.23 g CH_4/scf methane mass conversion.
- **Methane-intensity change:** Apply the difference between the baseline methane intensity of 1.71% and the low-leak target of 0.20%.

- **Avoided methane**: The modeled procurement shift avoids approximately 119,000 tons CH_4/year.
- **Climate impact:** Avoided methane is converted to CO_2e using fossil methane GWP20 = 82.5, resulting in approximately 9.8 million tons CO_2e/year avoided.
- **VOC proxy for health screening:** Avoided methane is translated to associated upstream VOC reductions using EPA's rule-wide ratio of 16 million tons VOC / 58 million tons methane, resulting in approximately 33,000 tons VOC/year entered in COBRA.
- **COBRA setup:** COBRA run uses the 2023 baseline, Texas as the location, and the closest available upstream oil-and-gas production sector. The resulting monetized health benefit is approximately $35 million/year.

Cost

- **Incremental low-leak procurement cost:** reported cost of $0.01 to $0.12/MMBtu for certified gas.

3. Key Calculations

- Methane represented by purchased gas = gas procurement × 10^6 ÷ methane heat content × methane mass conversion ÷ grams per short ton.
- Methane-intensity difference = baseline methane intensity − low-leak methane intensity.
- Avoided methane = methane represented by purchased gas × methane-intensity difference.
- Avoided CO_2e = avoided methane × fossil methane GWP20.
- VOC proxy input = avoided methane × EPA VOC-to-methane reduction ratio.

4. Key Limitations

- This is a procurement screening scenario, not a facility-level engineering retrofit model.
- The gas procurement denominator is a project estimate for target Texas chemical production and does not represent measured facility-level purchase contracts.
- The modeled methane benefit depends on the assumed upstream baseline methane intensity of 1.71% and target intensity of 0.20%.
- COBRA does not model methane directly; health benefits reflect associated upstream VOC reductions only.
- COBRA results do not value climate damages, methane-driven global background ozone, or hazardous air pollutants.
- The Texas statewide COBRA run is a geographic proxy for upstream supply; actual purchased gas may originate outside Texas.
- Results do not address market complexities such as physical delivery, certificate ownership, chain of custody, double counting, or certification-market availability.

5. Sources

- International Energy Agency Methane Tracker: methane abatement cost stack.
- EPA final oil and natural gas methane rule: methane and VOC co-reduction proxy.
- EPA COBRA Web Edition and COBRA methodology: health benefit screening.
- IPCC AR6 WG1, Chapter 7, Table 7.15: fossil methane GWP20.
- EIA methane heat content value: 1,010 Btu/scf.
- EPA methane unit conversion table: 1 scf methane = 19.23 g methane.

- Manufacturing Energy Consumption Survey, GHGRP, and RMI analysis: gas usage by chemical facilities in project scope.

NO_x Emissions Control Technologies

1. Scope

- Technologies: Low-NO_x burner and combustion-control retrofits (LNBs), selective catalytic reduction (SCR), and a stacked case that applies LNBs before SCR.
- Facility universe: 47 core facilities matched to 45 TCEQ emissions records.
- Modeled baseline: 22,000 tons NO_x/year from matched 2024 TCEQ point-source records.
- Eligible sources: Reported boilers, furnaces, and process heaters; flares, engines, turbines, process vents, and unmatched facilities are excluded.
- Interpretation: Incremental control-opportunity screen from current reported emissions; not an uncontrolled baseline, total chemical-sector inventory, or unit-level retrofit plan.

2. Methodology

Emissions

- **Inventory construction:** Audited facilities were mapped to TCEQ accounts and source rows; multiple records for one physical complex were combined, and unmatched sites were not imputed.
- **LNB central case:** Units with reported NO_x rates above 0.10 lb/MMBtu receive a 40% reduction; units at 0.04–0.10 lb/MMBtu receive 20%; lower-rate units receive no reduction. Missing-rate units receive an effective 10% reduction.
- **SCR central case:** Eligible units emitting at least 22.7 tons NO_x/year receive an 85% reduction. For units with missing rate fields, the model applies a limited effective SCR reduction of 21.25%.
- **Stacked case:** LNB reductions are applied first; SCR is then applied to the remaining emissions from screened candidates. Stand-alone LNB and SCR results should not be added.
- Central results: LNBs reduce 1,800 tons/year; SCR reduces 2,400 tons/year; the stacked case reduces 4,200 tons/year. Approximately 95% of the modeled reduction is associated with olefins facilities.

Cost and health benefits

• Annualized cost screen: LNB cost-effectiveness ranges from approximately $551 to $3,307 per ton removed (central: $1,653); SCR ranges from approximately $5,512 to $22,046 per ton (central: $11,023).

• Central annualized costs: $3.0 million/year for LNBs, $26.4 million/year for SCR, and $29.5 million/year for the stacked case. The stacked cost equals the LNB cost plus SCR cost on the screened portfolio.

• COBRA screen: A one-ton Texas chemical-sector NO_x reduction run produced low and high monetized benefits equivalent to approximately $32,200–$38,200 per ton. Midpoint benefits are $64.7 million/year for LNBs, $84.4 million/year for SCR, and $149.1 million/year for the stacked case.

3. Key Calculations

- LNB reduction = sum of current unit NO_x × applicable rate-class reduction.
- Stand-alone SCR reduction = sum of eligible current unit NO_x × applicable SCR reduction.
- Stacked reduction = LNB reduction + SCR reduction applied to post-LNB residual emissions.

- Annualized control cost = modeled reduction × annualized cost-effectiveness input; all cost inputs were converted to dollars per ton for reporting.
- COBRA health benefit = modeled reduction × midpoint monetized benefit per ton.

4. Key Limitations

- Reported emission-rate limits are screening proxies and do not prove whether a unit already has LNBs, ultra-low-NO_x burners, SCR, or other controls.
- Missing control and rate fields materially affect results; central effective reductions for unknown units are judgment-based.
- The baseline covers matched 2024 public records only and excludes unmatched facilities and noneligible source types.
- SCR feasibility is not screened for exhaust temperature, catalyst compatibility, ammonia handling, ductwork, space, unit age, remaining life, or outage timing.
- Annualized $/ton ranges are policy-scale screening assumptions, not engineering estimates; they do not provide a capital/O&M split or unit-specific retrofit cost.
- COBRA values are extrapolated from a one-ton screening run. The county-level scenario input tables should be rerun and imported before final publication; COBRA also does not capture all localized or worker-exposure effects.
- The stacked case represents broad technical opportunity, not an optimized deployment sequence or forecast of achievable adoption.

5. Sources

- TCEQ, Point Source Emissions Data and 2024 Point Source Data: unit/source NOx, equipment profiles, reported limits, and county.
- US EPA, NOx Emissions from Process Heaters: LNB/SCR performance and cost context.
- US EPA, SCR Cost Manual and Cost Equations: control-cost methodology and future unit-level upgrades.
- US EPA, Non-EGU NOx Control Assessment: control-efficiency and cost ranges.
- US EPA, COBRA Screening Model: monetized PM2.5- and ozone-related health benefits.

Thermal Energy Storage (TES) for Industrial Steam

1. Scope

- **Technology:** Electric thermal energy storage (TES) replacing steam supplied by conventional natural gas boilers.
- **Included processes:** Steam cracking and other olefins, non-refinery BTX, hydrogen, methanol, and ammonia.
- **Modeled Texas heat demand denominator:** 45.1 million MMBtu/year of natural gas boiler fuel, equivalent to 36.1 million MMBtu/year of useful steam heat.
- **Boundary:** Includes conventional natural gas boiler steam; excludes feedstock use, CHP/cogeneration, direct-fired process heat, purchased steam, and non-natural gas boiler fuel.

- **Interpretation:** Gross statewide technical-potential screen assuming full displacement of eligible boiler load; not an estimate of achievable or near-term deployment.

2. **Methodology**

Emissions

- **Demand denominator:** Start with national natural gas fuel estimates by target process; allocate to Texas using production, capacity, facility, and GHGRP-based activity indicators; apply process-specific conventional-boiler shares from EIA 2022 MECS Table 5.2; convert fuel to useful heat at 80% boiler efficiency.
- **Natural gas baseline:** Boiler fuel × 53.06 kg CO_2/MMBtu = 2.4 million tons CO_2/year.
- **TES electricity demand:** Useful heat × 293.071 kWh/MMBtu ÷ 98% efficiency = 10.79 TWh/year.
- **Current-grid case:** Electricity demand × Texas 2024 average generation intensity (0.373 kg CO_2/kWh) = 4 million tons CO_2/year, or 1.6 million tons above the gas baseline.
- **Zero-emissions case:** Charging intensity = 0 kg CO_2/kWh; avoided boiler emissions = 2.39 million tons CO_2/year.
- On-site air pollutants: NO_x, VOC, SO_2, and $PM_{2.5}$ reductions use EPA AP-42 screening factors and do not reflect boiler-specific controls.

Cost

- **Primary comparison:** Energy cost only — natural gas fuel for boiler heat versus electricity for TES heat. TES capital, fixed O&M, interconnection, and installation costs are excluded.
- **Average 2025 prices**: Gas at $3.72/MCF yields boiler heat at $4.48/MMBtu; electricity at $65.50/MWh yields TES heat at $19.59/MMBtu. Annual energy expenditure rises from $162 million to $707 million, a $545 million premium.
- **Favorable energy-price scenario:** 2022 gas at $6.61/MCF yields boiler heat at $7.97/MMBtu; TES charging at $30/MWh yields TES heat at $8.97/MMBtu, a 12.6% or $36 million annual premium.
- Interpretation: Results are not a levelized cost of heat or full project-cost comparison.

3. Key Calculations

- **Eligible useful heat** = state-allocated process fuel × conventional-boiler share × boiler efficiency.
- **Gas heat cost** = gas price ÷ natural gas energy content ÷ boiler efficiency.
- **TES heat energy cost** = electricity price × 0.293071 MWh/MMBtu ÷ TES efficiency.
- **TES electricity demand** = useful heat × 293.071 kWh/MMBtu ÷ TES efficiency.
- **Energy-only abatement cost** = incremental electricity expenditure ÷ operational CO_2 avoided.
- **Illustrative infrastructure requirement:** 19.3 GWh of thermal storage and 3.70 GW of electric charging capacity.

4. Key Limitations

- National MECS boiler shares and state activity allocations are screening proxies, not measured facility steam consumption.
- Full displacement does not account for technical suitability, steam conditions, load shape, redundancy, retrofit timing, or site constraints.
- Current-grid emissions use annual-average generation intensity rather than hourly marginal emissions; low-price hours are not assumed to be low-emissions hours.
- The $30/MWh case is an illustrative final all-in price, not an available tariff or market forecast.

- Energy-only economics exclude equipment, O&M, interconnection, electrical upgrades, steam integration, installation, engineering, contingency, and financing.
- Infrastructure sizing assumes a flat average load and an eight-hour daily charging period.

5. Sources

- EIA 2022 Manufacturing Energy Consumption Survey, Table 5.2: Conventional-boiler fuel shares.
- EIA Natural Gas Navigator: 2022 and 2025 Texas industrial natural gas prices.
- EIA Electric Power Monthly, Table 5.6.B: 2025 Texas industrial electricity price.
- EIA Texas State Electricity Profile, 2024: Average grid generation emissions.
- EPA GHG Emission Factors Hub: Natural gas CO_2 factor.
- EPA AP-42, Section 1.4: Natural gas boiler air-pollutant factors.

High-Purity CCS for Hydrogen and Related Primary Chemical Production

1. Scope

- **Technology:** Carbon capture and storage applied to high-purity process CO_2 streams associated with hydrogen and related primary chemical production.
- **Included processes in the model:** Hydrogen, ammonia, and methanol.
- **Modeled Texas facility count:** 15 hydrogen facilities, 2 ammonia facilities, and 3 methanol facilities.
- **Modeled cases:**
    a. **Texas + CCS:** CCS deployed using the current Texas grid emissions factor for added electricity demand.
    b. **Texas Renewable + CCS:** CCS deployed assuming 100% renewable electricity for added electricity demand.
- **Interpretation:** Statewide screening estimate of emissions-reduction potential from CCS on high-purity process streams. This is not a facility-specific engineering design or a full project-level investment estimate.

2. Methodology

Emissions

- **Baseline emissions intensity:** Start with RMI's internal *Chemistry in Transition* emissions model for baseline emissions intensities by primary chemical.
- **CCS case emissions intensity:** Apply CCS-adjusted emissions intensities for hydrogen, ammonia, and methanol.
- **Statewide reduction:** Multiply the change in emissions intensity by average production volume and the number of facilities in Texas.
- **Grid case:** Uses Texas grid electricity emissions for added CCS electricity demand.
- **Renewable case:** Assumes added CCS electricity demand is supplied by 100% renewable electricity.
- **GHGs**

a. Percent reduction from Texas primary chemicals baseline:
    i. Texas + CCS: 5.8%.
    ii. Texas Renewable + CCS: 6.7%.

- **Air pollutants**
    a. The model estimates changes in VOC, CO, NOx, PM10, PM2.5, SOx, and CH_4.
    b. In the Texas + CCS grid-powered case, several CAPs increase because added CCS energy demand increases upstream or power-sector emissions.
    c. Total CAPs reduction in the renewable case is approximately 0.9%.

Cost

- **Estimated statewide capex:** $4.95 billion.
- **Statewide annual cost before 45Q:** $857 million/year.
- **Cost per net ton CO_2e avoided before 45Q:** $129/t$CO_2e$.
- **Statewide annual net cost after $85/t 45Q:** $293 million/year.
- **Cost per net ton CO_2e avoided after $85/t 45Q:** $44/t$CO_2e$.
- **Interpretation:** Cost results are screening-level estimates and do not include full project-finance, tax-equity, site-specific engineering, pipeline, storage, or transaction-cost detail beyond what is represented in the model.

3. Key Calculations

- **Texas statewide primary chemicals baseline emissions** = baseline emissions intensity × average production volume × number of facilities.
- **CCS case emissions** = CCS-adjusted emissions intensity × average production volume × number of facilities.
- **GHG reduction** = baseline emissions − CCS case emissions.
- **Percent reduction from primary chemicals baseline** = total GHG reduction ÷ Texas statewide primary chemicals baseline emissions.
- **Statewide annual cost after 45Q** = annual cost before 45Q − value of 45Q credit.
- **Cost per net ton CO_2e** = annual cost ÷ net CO_2e avoided.

4. Key Limitations

- The model is a statewide screening analysis, not a facility-specific CCS deployment plan.
- Facility production is estimated using average production volumes and facility counts, not measured facility-level production.
- Results depend on RMI's internal *Chemistry in Transition* emissions model and CCS-adjusted emissions intensities.
- The grid-powered CCS case can increase some criteria air pollutants due to added energy demand.
- The renewable case assumes 100% renewable electricity for added CCS load and does not evaluate hourly matching, interconnection, or electricity procurement constraints.
- CAP and CH_4 results are directional screening estimates and should not be interpreted as permit-level emissions estimates.

- Cost results do not include project-specific pipeline distance, storage-site availability, permitting, pore-space access, financing structure, tax-credit monetization, or liability considerations.
- The 45Q sensitivity assumes an $85/ton credit value but does not model eligibility, transfer discounts, tax appetite, transaction costs, or credit sharing.

5. **Sources**
   - RMI internal emissions and cost modeling
   - EPA GHGRP / FLIGHT: facility-level greenhouse gas reporting framework.
   - DOE/NETL, Cost of Capturing CO_2 from Industrial Sources: capture cost and energy assumptions.
   - EPA eGRID: grid emissions factors.
   - EPA GHG Emission Factors Hub: natural gas combustion emissions factors.
   - IPCC AR6: fossil methane GWP assumptions.
   - IRS 45Q guidance: carbon oxide sequestration credit sensitivity.

COBRA Assumptions & Outputs

AI-Driven Predictive Maintenance

Exhibit 1: COBRA assumptions for AI-driven predictive maintenance

Counties	Brazoria, Calhoun, Chambers, Fort Bend, Galveston, Gregg, Harris, Harrison, Hutchinson, Jefferson, Montgomery, Nueces, Orange, San Patricio
Sector/Subsectors	Chemical & Allied Product > Organic Chemical
Discount rate	2%
$PM_{2.5}$ reduce by (short tons)	0.08
SO_2 reduce by (short tons)	0.08
NO_x reduce by (short tons)	29.40
VOC reduce by (short tons)	150.44

Exhibit 2: COBRA outputs for AI-driven predictive maintenance

Total Annual Health Benefits to Texas		
	$1,301,407	**$1,478,030**
	Low Value	**High Value**
	Change in Incidence	**Monetary Value**
Total Mortality	**0.074 / 0.086**	**$1,084,467 / $1,261,090**

Mortality, All Cause (PM)	0.009 / 0.021	$133,818 / $310,441
Mortality, O3 Short-term Exposure (O3)	0.003	$40,918
Mortality, O3 Long-term Exposure (O3)	0.062	$909,731
Nonfatal Heart Attacks (PM)	**0.006**	**$518**
Infant Mortality (PM)	**0.000**	**$2,021**
Total Hospital Admits, All Respiratory	**0.009**	**$164**
Hospital Admits, All Respiratory (PM)	0.001	$32
Hospital Admits, All Respiratory (O3)	0.007	$132
Total Emergency Room Visits, Respiratory	**0.283**	**$460**
Emergency Room Visits, Respiratory (PM)	0.011	$18
Emergency Room Visits, Respiratory (O3)	0.272	$443
Total Asthma Onset	**0.741**	**$56,536**
Asthma Onset (PM)	0.038	$2,906
Asthma Onset (O3)	0.703	$53,629
Total Asthma Symptoms	**111.680**	**$40,452**
Asthma Symptoms, Albuterol Use (PM)	6.836	$4
Asthma Symptoms, Chest Tightness (O3)	28.886	$11,144
Asthma Symptoms, Cough (O3)	34.073	$13,145
Asthma Symptoms, Shortness of Breath (O3)	14.577	$5,624
Asthma Symptoms, Wheeze (O3)	27.308	$10,535
Emergency Room Visits, Asthma (O3)	**0.001**	**$1**
Lung Cancer (PM)	**0.001**	**$32**
Hospital Admits, Cardio-Cerebro/Peripheral Vascular Disease (PM)	**0.001**	**$37**
Hospital Admits, Alzheimer's Disease (PM)	**0.002**	**$55**
Hospital Admits, Parkinson's Disease (PM)	**0.001**	**$13**
Stroke (PM)	**0.001**	**$38**
Total Hay Fever/Rhinitis	**4.646**	**$5,176**
Hay Fever/Rhinitis (PM)	0.237	$264
Hay Fever/Rhinitis (O3)	4.409	$4,912
Cardiac Arrest, Out of Hospital (PM)	**0.000**	**$10**
Emergency Room Visits, All Cardiac (PM)	**0.004**	**$8**
Minor Restricted Activity Days (PM)	**9.995**	**$1,257**
School Loss Days (O3)	**64.547**	**$109,621**
Work Loss Days (PM)	**1.703**	**$539**
Total PM Health Effects	**18.847 / 18.859**	**$141,571 / $318,194**
Total O3 Health Effects	**174.849**	**$1,159,835**

Low-Leak Natural Gas Procurement

Exhibit 3: COBRA assumptions for low-leak gas

Counties	Texas (all)
Sector/Subsectors	Petroleum & Related Industries > Oil and Gas production
Discount rate	2%
VOC reduce by (short tons)	36,300

Exhibit 4: COBRA outputs for low-leak gas

Total Annual Health Benefits to Texas		
	$38,437,989	**$38,437,989**
	Low Value	**High Value**
	Change in Incidence	**Monetary Value**
Total Mortality	**2.182 / 2.182**	**$31,849,988 / $31,849,988**
Mortality, All Cause (PM)	0.000 / 0.000	$0 / $0
Mortality, O3 Short-term Exposure (O3)	0.094	$1,370,865
Mortality, O3 Long-term Exposure (O3)	2.088	$30,479,123
Nonfatal Heart Attacks (PM)	**0.000**	**$0**
Infant Mortality (PM)	**0.000**	**$0**
Total Hospital Admits, All Respiratory	**0.248**	**$4,459**
Hospital Admits, All Respiratory (PM)	0.000	$0
Hospital Admits, All Respiratory (O3)	0.248	$4,459
Total Emergency Room Visits, Respiratory	**8.748**	**$14,209**
Emergency Room Visits, Respiratory (PM)	0.000	$0
Emergency Room Visits, Respiratory (O3)	8.748	$14,209
Total Asthma Onset	**22.074**	**$1,683,724**
Asthma Onset (PM)	0.000	$0
Asthma Onset (O3)	22.074	$1,683,724
Total Asthma Symptoms	**3,286.269**	**$1,267,816**
Asthma Symptoms, Albuterol Use (PM)	0.000	$0
Asthma Symptoms, Chest Tightness (O3)	905.373	$349,286
Asthma Symptoms, Cough (O3)	1,068.008	$412,029
Asthma Symptoms, Shortness of Breath (O3)	456.924	$176,278
Asthma Symptoms, Wheeze (O3)	855.964	$330,224
Emergency Room Visits, Asthma (O3)	**0.047**	**$39**
Lung Cancer (PM)	**0.000**	**$0**
Hospital Admits, Cardio-Cerebro/Peripheral Vascular Disease (PM)	**0.000**	**$0**
Hospital Admits, Alzheimer's Disease (PM)	**0.000**	**$0**
Hospital Admits, Parkinson's Disease (PM)	**0.000**	**$0**
Stroke (PM)	**0.000**	**$0**
Total Hay Fever/Rhinitis	**139.124**	**$155,013**
Hay Fever/Rhinitis (PM)	0.000	$0

Hay Fever/Rhinitis (O3)	139.124	$155,013
Cardiac Arrest, Out of Hospital (PM)	**0.000**	**$0**
Emergency Room Visits, All Cardiac (PM)	**0.000**	**$0**
Minor Restricted Activity Days (PM)	**0.000**	**$0**
School Loss Days (O3)	**2,038.929**	**$3,462,741**
Work Loss Days (PM)	**0.000**	**$0**
Total PM Health Effects	**0.000 / 0.000**	**$0 / $0**
Total O3 Health Effects	**5,497.620**	**$38,437,989**

NO_x Controls

Exhibit 5: COBRA assumptions for NO_x controls

Counties	Brazoria, Calhoun, Chambers, Fort Bend, Galveston, Gregg, Harris, Harrison, Hutchinson, Jefferson, Montgomery, Nueces, Orange, San Patricio
Sector/Subsectors	Chemical & Allied Product > Organic Chemical
Discount rate	2%
$PM_{2.5}$ reduce by (short tons)	0
SO_2 reduce by (short tons)	0
NO_x reduce by (short tons)	1.00
VOC reduce by (short tons)	0

Exhibit 6: COBRA outputs for NO_x controls

Total Annual Health Benefits to Texas		
	$29,208	**$34,661**
	Low Value	**High Value**
	Change in Incidence	**Monetary Value**
Total Mortality	**0.002 / 0.002**	**$24,630 / $30,082**
Mortality, All Cause (PM)	0.000 / 0.001	$4,136 / $9,588
Mortality, O3 Short-term Exposure (O3)	0.000	$882
Mortality, O3 Long-term Exposure (O3)	0.001	$19,612
Nonfatal Heart Attacks (PM)	**0.000**	**$16**
Infant Mortality (PM)	**0.000**	**$62**
Total Hospital Admits, All Respiratory	**0.000**	**$4**
Hospital Admits, All Respiratory (PM)	0.000	$1
Hospital Admits, All Respiratory (O3)	0.000	$3
Total Emergency Room Visits, Respiratory	**0.006**	**$10**

Emergency Room Visits, Respiratory (PM)	0.000	$1
Emergency Room Visits, Respiratory (O3)	0.006	$9
Total Asthma Onset	**0.016**	**$1,200**
Asthma Onset (PM)	0.001	$89
Asthma Onset (O3)	0.015	$1,110
Total Asthma Symptoms	**2.384**	**$839**
Asthma Symptoms, Albuterol Use (PM)	0.210	$0
Asthma Symptoms, Chest Tightness (O3)	0.599	$231
Asthma Symptoms, Cough (O3)	0.706	$273
Asthma Symptoms, Shortness of Breath (O3)	0.302	$117
Asthma Symptoms, Wheeze (O3)	0.566	$218
Emergency Room Visits, Asthma (O3)	**0.000**	**$0**
Lung Cancer (PM)	**0.000**	**$1**
Hospital Admits, Cardio-Cerebro/Peripheral Vascular Disease (PM)	**0.000**	**$1**
Hospital Admits, Alzheimer's Disease (PM)	**0.000**	**$2**
Hospital Admits, Parkinson's Disease (PM)	**0.000**	**$0**
Stroke (PM)	**0.000**	**$1**
Total Hay Fever/Rhinitis	**0.099**	**$110**
Hay Fever/Rhinitis (PM)	0.007	$8
Hay Fever/Rhinitis (O3)	0.091	$102
Cardiac Arrest, Out of Hospital (PM)	**0.000**	**$0**
Emergency Room Visits, All Cardiac (PM)	**0.000**	**$0**
Minor Restricted Activity Days (PM)	**0.307**	**$39**
School Loss Days (O3)	**1.339**	**$2,273**
Work Loss Days (PM)	**0.052**	**$17**
Total PM Health Effects	**0.579 / 0.580**	**$4,374 / $9,826**
Total O3 Health Effects	**3.625**	**$24,830**

Thermal Energy Storage

Exhibit 7: COBRA assumptions for TES with 100% renewable energy

Counties	Brazoria, Calhoun, Chambers, Fort Bend, Galveston, Gregg, Harris, Harrison, Hutchinson, Jefferson, Mongomery, Nueces, Orange, San Patricio
Sector/Subsectors	Chemical > Organic
Discount rate	2%
$PM_{2.5}$ reduce by (short tons)	168.1
SO_2 reduce by (short tons)	13.27
NO_x reduce by (short tons)	2,211.8
VOC reduce by (short tons)	121.6

Exhibit 8: COBRA outputs for TES with 100% renewable energy

Total Annual Health Benefits to Texas		
	$90,017281	**$133,642,837**
	Low Value	**High Value**
	Change in Incidence	**Monetary Value**
Total Mortality	5.37 / 8.359	$78,383,986 / $122,009,542
Mortality, All Cause (PM)	2.246 / 5.234	32,771,182 / 76,396,739
Mortality, O3 Short-term Exposure (O3)	0.134	$1,962,920
Mortality, O3 Long-term Exposure (O3)	2.99	$43,649,885
Nonfatal Heart Attacks (PM)	1.52	$127,835
Infant Mortality (PM)	0.033	$517,461
Total Hospital Admits, All Respiratory	0.654	$14,307
Hospital Admits, All Respiratory (PM)	0.307	$8,069
Hospital Admits, All Respiratory (O3)	0.347	$6,238
Total Emergency Room Visits, Respiratory	15.414	$25,039
Emergency Room Visits, Respiratory (PM)	2.796	$4,541
Emergency Room Visits, Respiratory (O3)	12.62	$20,498
Total Asthma Onset	42.186	$3,217,783
Asthma Onset (PM)	9.771	$745,274
Asthma Onset (O3)	32.415	$2,472,510
Total Asthma Symptoms	**6,590.275**	**$1,868,833**
Asthma Symptoms, Albuterol Use (PM)	1,749.029	$1,119
Asthma Symptoms, Chest Tightness (O3)	1,333.746	$514,549
Asthma Symptoms, Cough (O3)	1,573.378	$606,997
Asthma Symptoms, Shortness of Breath (O3)	673.137	$259,691
Asthma Symptoms, Wheeze (O3)	1,260.984	$486,477
Emergency Room Visits, Asthma (O3)	**0.067**	**$56**
Lung Cancer (PM)	**0.183**	**$7,914**
Hospital Admits, Cardio-Cerebro/Peripheral Vascular Disease (PM)	**0.322**	**$9,253**
Hospital Admits, Alzheimer's Disease (PM)	**0.605**	**$13,523**
Hospital Admits, Parkinson's Disease (PM)	**0.14**	**$3,335**
Stroke (PM)	**0.149**	**$9,411**
Total Hay Fever/Rhinitis	**264.308**	**$294,494**
Hay Fever/Rhinitis (PM)	60.754	$67,692
Hay Fever/Rhinitis (O3)	203.554	$226,801
Cardiac Arrest, Out of Hospital (PM)	**0.041**	**$2,500**
Emergency Room Visits, All Cardiac (PM)	**0.95**	**$2,048**
Minor Restricted Activity Days (PM)	**2,540.844**	**$319,435**

School Loss Days (O3)	**2,981.189**	**$5,062,995**
Work Loss Days (PM)	**433.345**	**$137,076**
Total PM Health Effects	**4,803.031 / 4,806.019**	**$34,747,666 / $78,373,222**
Total O3 Health Effects	**8,074.564**	**$55,269,616**

CCS on Hydrogen

Exhibit 9: COBRA assumptions for CCS with 2024 Texas grid mix

Counties	Brazoria, Galveston, Gregg, Harris, Hutchinson, Jefferson, Nueces
Sector/Subsectors	Fuel combustion: electric utility > All
Discount rate	2%
$PM_{2.5}$ increase by (short tons)	14.3
SO_2 increase by (short tons)	143.8
NO_x increase by (short tons)	293.1
VOC increase by (short tons)	79.5

Exhibit 10: COBRA outputs for CCS with 2024 Texas grid mix

Total Annual Health Benefits to Texas		
	-$15,645,059	**-$23,077,693**
	Low Value	**High Value**
	Change in Incidence	**Monetary Value**
Total Mortality	**-0.924 / -1.433**	**-$13,481,774 / -$20,914,408**
Mortality, All Cause (PM)	-0.382 / -0.892	-$5,581,178 / -$13,013,812
Mortality, O3 Short-term Exposure (O3)	-0.023	-$340,171
Mortality, O3 Long-term Exposure (O3)	-0.518	-$7,560,426
Nonfatal Heart Attacks (PM)	**-0.259**	**-$21,788**
Infant Mortality (PM)	**-0.006**	**-$88,794**
Total Hospital Admits, All Respiratory	**-0.115**	**-$2,508**
Hospital Admits, All Respiratory (PM)	-0.052	-$1,378
Hospital Admits, All Respiratory (O3)	-0.063	-$1,130
Total Emergency Room Visits, Respiratory	**-2.845**	**-$4,622**
Emergency Room Visits, Respiratory (PM)	-0.478	-$777
Emergency Room Visits, Respiratory (O3)	-2.367	-$3,846
Total Asthma Onset	**-7.813**	**-$595,970**
Asthma Onset (PM)	-1.671	-$127,491
Asthma Onset (O3)	-6.142	-$468,480

Total Asthma Symptoms	**-1213.385**	**-$352,954**
Asthma Symptoms, Albuterol Use (PM)	-299.000	-$191
Asthma Symptoms, Chest Tightness (O3)	-251.926	-$97,191
Asthma Symptoms, Cough (O3)	-297.160	-$114,642
Asthma Symptoms, Shortness of Breath (O3)	-127.133	-$49,047
Asthma Symptoms, Wheeze (O3)	-238.166	-$91,883
Emergency Room Visits, Asthma (O3)	**-0.013**	**-$11**
Lung Cancer (PM)	**-0.031**	**-$1,349**
Hospital Admits, Cardio-Cerebro/Peripheral Vascular Disease (PM)	**-0.055**	**-$1,577**
Hospital Admits, Alzheimer's Disease (PM)	**-0.103**	**-$2,308**
Hospital Admits, Parkinson's Disease (PM)	**-0.024**	**-$568**
Stroke (PM)	**-0.025**	**-$1,603**
Total Hay Fever/Rhinitis	**-48.844**	**-$54,422**
Hay Fever/Rhinitis (PM)	-10.387	-$11,574
Hay Fever/Rhinitis (O3)	-38.456	-$42,848
Cardiac Arrest, Out of Hospital (PM)	**-0.007**	**-$426**
Emergency Room Visits, All Cardiac (PM)	**-0.162**	**-$349**
Minor Restricted Activity Days (PM)	**-434.800**	**-$54,663**
School Loss Days (O3)	**-562.858**	**-$955,910**
Work Loss Days (PM)	**-74.172**	**-$23,462**
Total PM Health Effects	**-821.615 / -822.125**	**-$5,919,476 / -$13,352,110**
Total O3 Health Effects	**-1524.826**	**-$9,725,583**

Exhibit 11: COBRA assumptions for CCS with 100% renewable energy

Counties	Brazoria, Galveston, Gregg, Harris, Hutchinson, Jefferson, Nueces
Sector/Subsectors	Fuel combustion: electric utility > All
Discount rate	2%
$PM_{2.5}$ reduce by (short tons)	4.8
SO_2 reduce by (short tons)	39.7
NO_x reduce by (short tons)	72.6
VOC reduce by (short tons)	16.2

Exhibit 12: COBRA outputs for CCS with 100% renewable energy

Total Annual Health Benefits to Texas		
	$4,137,745	**$6,327,497**
	Low Value	**High Value**

	Change in Incidence	Monetary Value
Total Mortality	**0.246 / 0.396**	**$3,588,357 / $5,778,109**
Mortality, All Cause (PM)	0.113 / 0.263	$1,642,433 / $3,832,185
Mortality, O3 Short-term Exposure (O3)	0.006	$83,787
Mortality, O3 Long-term Exposure (O3)	0.128	$1,862,137
Nonfatal Heart Attacks (PM)	**0.076**	**$6,415**
Infant Mortality (PM)	**0.002**	**$26,267**
Total Hospital Admits, All Respiratory	**0.031**	**$685**
Hospital Admits, All Respiratory (PM)	0.015	$407
Hospital Admits, All Respiratory (O3)	0.015	$278
Total Emergency Room Visits, Respiratory	**0.724**	**$1,176**
Emergency Room Visits, Respiratory (PM)	0.141	$229
Emergency Room Visits, Respiratory (O3)	0.583	$947
Total Asthma Onset	**2.007**	**$153,052**
Asthma Onset (PM)	0.494	$37,693
Asthma Onset (O3)	1.512	$115,359
Total Asthma Symptoms	**313.556**	**$86,928**
Asthma Symptoms, Albuterol Use (PM)	88.378	$57
Asthma Symptoms, Chest Tightness (O3)	62.039	$23,934
Asthma Symptoms, Cough (O3)	73.180	$28,232
Asthma Symptoms, Shortness of Breath (O3)	31.308	$12,079
Asthma Symptoms, Wheeze (O3)	58.651	$22,627
Emergency Room Visits, Asthma (O3)	**0.003**	**$3**
Lung Cancer (PM)	**0.009**	**$398**
Hospital Admits, Cardio-Cerebro/Peripheral Vascular Disease (PM)	**0.016**	**$464**
Hospital Admits, Alzheimer's Disease (PM)	**0.030**	**$679**
Hospital Admits, Parkinson's Disease (PM)	**0.007**	**$167**
Stroke (PM)	**0.007**	**$472**
Total Hay Fever/Rhinitis	**12.541**	**$13,973**
Hay Fever/Rhinitis (PM)	3.071	$3,421
Hay Fever/Rhinitis (O3)	9.470	$10,552
Cardiac Arrest, Out of Hospital (PM)	**0.002**	**$126**
Emergency Room Visits, All Cardiac (PM)	**0.048**	**$103**
Minor Restricted Activity Days (PM)	**128.439**	**$16,147**
School Loss Days (O3)	**138.609**	**$235,401**
Work Loss Days (PM)	**21.913**	**$6,931**
Total PM Health Effects	**242.761 / 242.911**	**$1,742,409 / $3,932,161**
Total O3 Health Effects	**375.504**	**$2,395,335**