



ENERGY SYSTEMS LABORATORY
TEXAS A&M ENGINEERING EXPERIMENT STATION

Energy Efficiency and Renewable Energy Impacts on NOx Emission Reductions in Texas

Jeff Haberl, Ph.D.

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Bahman Yazdani, P.E.



**TEXAS ENERGY
SUMMIT**

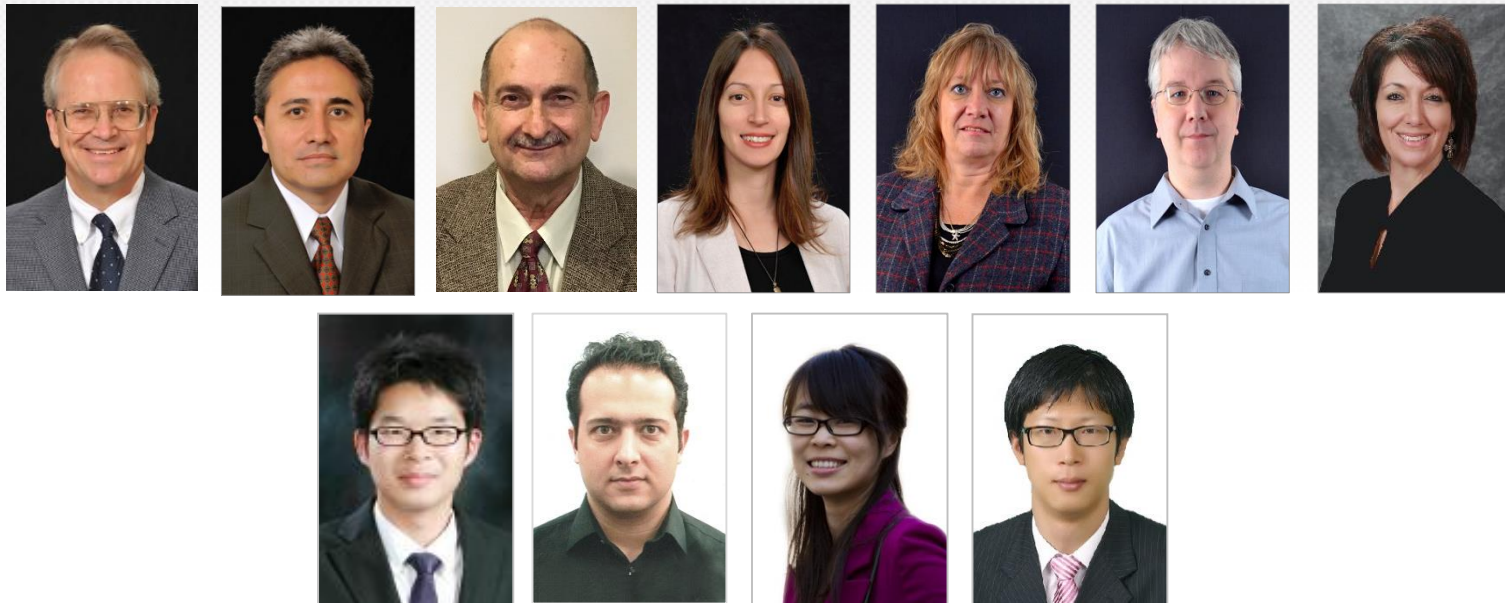
Texas State Capitol in Austin, Texas

November 12-14, 2019

ACKNOWLEDGEMENTS

Faculty/Staff: Jeff Haberl, Juan-Carlos Baltazar, Bahman Yazdani, Gali Zilbershtein, Shirley Ellis, Patrick Parker, Angela Rowell

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PUCT: Katie Rich, Therese Harris

SECO: Dub Taylor, Stephen Ross

ERCOT: Paul Wattles, Connor Anderson

LEGISLATION

Legislation to Reduce Energy/Emissions 2001 to Present

Senate Bill 5 (77th Legislature, 2001)

- Ch. 386. Texas Emissions Reduction Plan
 - Sec. 386.205. Evaluation Of State Energy Efficiency Programs (with PUC)
- Ch. 388. Texas Building Energy Performance Standards
 - Sec. 388.003. Adoption Of Building Energy Efficiency Performance Standards.
 - Sec. 388.004. Enforcement Of Energy Standards Outside Of Municipality.
 - Sec. 388.007. Distribution Of Information And Technical Assistance.
 - Sec. 388.008. Development Of Home Energy Ratings.

TERP Amended (78th Legislature, 2003)

- Ch. 388. Texas Building Energy Performance Standards
 - (HB 1365) Sec. 388.004. Enforcement Of Energy Standards Outside Of Municipality.
 - (HB 1365) Sec. 388.009. Energy-Efficient Building Program.
- Ch. 388. Texas Building Energy Performance Standards
 - (HB 3235) Sec. 388.009. Certification of Municipal Inspectors.

TERP Amended (79th Legislature, 2005)

- Ch. 382. Health and Safety Code
 - (HB 2129) Sec. 386.056 Development of Creditable Statewide emissions from wind and other renewables.
 - (HB 965) Sec. 382.0275 Commission Action Relating to Water Heaters

TERP Amended (80th Legislature, 2007)

- Ch. 382. Health and Safety Code
 - (HB 3693) Sec. 388.003 added subsection (b-1), (b-2), (b-3) that allows SECO to adopt new editions of the IECC based on written recommendations from the Laboratory.
 - (HB 3693) Sec. 388.008 Development of Standardized report formats for newly constructed residences.
- Ch. 386.252 Health and and Safety Code
 - (SB 12) Section 388.03 added subsection (b-1), (b-2) allows SECO to adopt new editions of the IECC based on written recommendations from the Laboratory.

TERP Amended (81st Legislature, 2009)

- Ch. 382. Health and Safety Code
 - (HB 1796) Section 23 amends Sec. 386.252 (a) and (b) extends date of TERP to 2019 and requires Commission to contract with Laboratory for creditable EE/RE emissions reductions.

TERP Amended (82nd Legislature, 2011)

- Ch. 477.004 Health and Safety Code
 - HB 51 Section 2, b-2, establishes advisory committee, which including the Laboratory
 - Section 3 & 4 amends review of municipal's amendments.
- Ch. 388.003e & 388.007c,d Health and Safety Code
 - HB 51 Section 3 & 4 amends review of municipal's amendments.
- Ch. 388.006 Health and Safety Code
 - SB 898 Section 2, requires the Laboratory to calculate energy savings and emissions reductions for political subdivisions reporting to SECO.
- Ch. 39.9051 Utilities Code
 - SB 924 Section 1g,h and Section 2c,d requires the Laboratory to calculate energy savings and emissions reductions for political subdivisions reporting to SECO.

NO new amendments were passed (83rd Legislature, 2013)

TERP Amended (84th Legislature, 2015)

- Section 388.003, Health and Safety Code
 - HB 1736 Section 1 Establishes the 2015 energy codes as the TBEPS effective Sept 1, 2016. The state may adopt new codes no sooner than every 6 years. The section also adds Energy Rating Index as a voluntary compliance alternative.

NO new amendments were passed (85th Legislature, 2017)

NO new amendments were passed (86th Legislature, 2019)



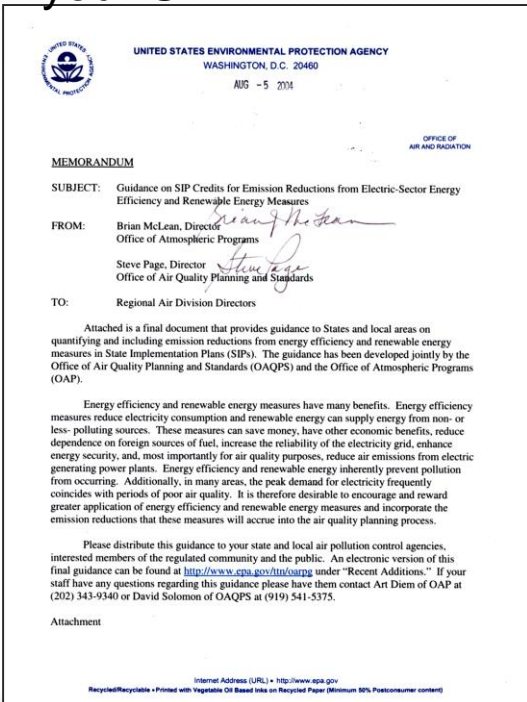
EPA CRITERIA FOR SIP CREDITS (2004)

Quantifiable: The emission reductions generated by measures to reduce emissions *must be quantifiable* and include procedures to evaluate and verify over time the level of emission reductions actually achieved.

Surplus: Emission reductions *are surplus* as long as they are not otherwise relied on to meet air quality attainment requirements in air quality programs related to your SIP.

Enforceability: Measures that reduce emissions from electricity generation may be: (1) *Enforceable directly* against a source; (2) *Enforceable against another party* responsible for the energy efficiency or renewable energy activity; or (3) Included under our *voluntary measures* policy.

Record Keeping: The *measure should be permanent* throughout the term for which the credit is granted unless it is replaced by another measure or the State demonstrates in a SIP revision that the emission reductions from the measure are no longer needed to meet applicable requirements.



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ESL-TR-08-12-04

Estimation of Annual Reductions of NO_x Emissions in
ERCOT for the HB3693 Electricity Savings Goals

Presented to the Public Utility Commission of Texas

By the United States Environmental Protection Agency

Prepared by
the United States Environmental Protection Agency and
the Energy Systems Laboratory

December 2008

Enforceability: Measures that reduce emissions from electricity generation may be: (1) *Enforceable directly* against a source; (2) *Enforceable against another party* responsible for the energy efficiency or renewable energy activity; or (3) Included under our *voluntary measures* policy.

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ENERGY SAVINGS & NO_x EMISSION REDUCTION



ESL Calculates & Reports NO_x Emissions Reductions for:

- 1. Code-Compliant Construction:** Energy savings from new construction
 - ESL Single-family construction
 - ESL Multi-family construction
 - ESL Commercial construction
- 2. Green Power Production:** Wind and other renewables
- 3. PUC SB7:** Energy efficiency programs implemented by electric utilities under the Public Utility Regulatory Act §39.905
- 4. SECO:** Energy-efficiency programs towards school districts, government agencies, city and county governments, private industries and residential energy consumers
- 5. A/C Retrofits:** Installation of SEER 13/14 *replacement* air conditioners in existing residences

ENERGY SAVINGS & NO_x EMISSION REDUCTION



ESL Calculates & Reports NO_x Emissions Reductions for: Code-Compliant Construction: Energy savings from new construction

User Login

This is the publicly accessible energy code compliance software based on the Texas Building Energy Performance Standards. Version 4.4 has been released.

Important: Version 4.4 has drastically changed the ERI algorithm. The amount of calculation needed has more than doubled. An ERI calculation will now take up to 1 minute to complete.

Username: Please enter a username

Password: Please enter a password

[Register New User](#) [Forgot Password](#)

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[Credits](#) [Help/FAQ](#) [Manual](#) [IC3 v4.4.2](#) [RESNET Test Results](#)

Login Screen

ENERGY SAVINGS & NO_x EMISSION REDUCTION



ESL Calculates & Reports NO_x Emissions Reductions for:

Code-Compliant Construction: Energy savings from new construction

[Return to Project List](#)

Project Name: **Texas Energy Summit**

Simulation Mode: Performance Path ERI Simulation Path

Energy Code: 2015 IECC

Street Address: 1100 Congress Ave

County: TRAVIS

City: AUSTIN

Zip: xxxxx-xxxx

Builder Name: ESL

Builder Email: esl_e2calc_support@tees.ta

Builder Phone: xxx-xxx-xxxx

Notes: 2500 sqft, Single Family, All-Electric

When downloading the energy report, there are issues with browser plug-ins converting the .pdf to HTML5. See the link for details. [Help/FAQ](#)

Global Parameters

Number of Floors: 1

Number of Bedrooms: 4

Orientation of Unit Front Side: South

Exterior Finish Type: Brick

Window

SHGC: 0.25

U-Factor: 0.4

Insulation

Wall Cavity Insulation: R-15

Wall Continuous Insulation: R-0

Studs

Stud Type: 2 x 4

Ducts

Duct Systems Tested:

Supply Duct Insulation: R-8

Return Duct Insulation: R-8

Displayed Floor: 1

Left Side

Length of Wall (ft)	50
Window Area (sq ft)	93.75
Horizontal Shading (in)	0
Height of Wall (ft)	8

Front Side

Length of Wall (ft)	50
Window Area (sq ft)	93.75
Horizontal Shading (in)	0
Height of Wall (ft)	8

Left Side

Length of Wall (ft)	50
Window Area (sq ft)	93.75
Horizontal Shading (in)	0
Height of Wall (ft)	8

Right Side

Length of Wall (ft)	50
Window Area (sq ft)	93.75
Horizontal Shading (in)	0
Height of Wall (ft)	8

Conditioned Floor Area (sq ft)	2500
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Back Side

Length of Wall (ft)	50
Window Area (sq ft)	93.75
Horizontal Shading (in)	0
Height of Wall (ft)	8

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Credits Help/FAQ Manual IC3 v4.4.2 RESNET Test Results

Main Page

ENERGY SAVINGS & NO_x EMISSION REDUCTION



ESL Calculates & Reports NO_x Emissions Reductions for: Code-Compliant Construction: Energy savings from new construction

Residential Energy Efficiency Certificate		ENERGY SYSTEMS LABORATORY TEXAS A&M ENGINEERING EXPERIMENT STATION	
Window U-Value	U- 0.4	Duct Tightness (in CFM25)	100
Window SHGC	0.25	Cooling Efficiency	SEER 14
Wall Cavity Insulation	R - 15	Heating Efficiency	8.2 HSPF
Roof/Ceiling Insulation	R - 32	Water Heater Efficiency	Electric EF 0.904
Floor/Foundation Insulation	R - 0	Builder Email	xxxxx@tamu.edu
Supply Duct Insulation	R - 8	Builder Phone	xxx-xxx-xxxx
Return Duct Insulation	R - 8	Date Issued	10/2/2019
Blower Door (in ACH50)	5	Certificate Number	1,138,738
International CODE COMPLIANCE CALCULATOR		Builder or Registered Design Professional _____	
This certificate was generated by IC3 in compliance with 2015 IECC			



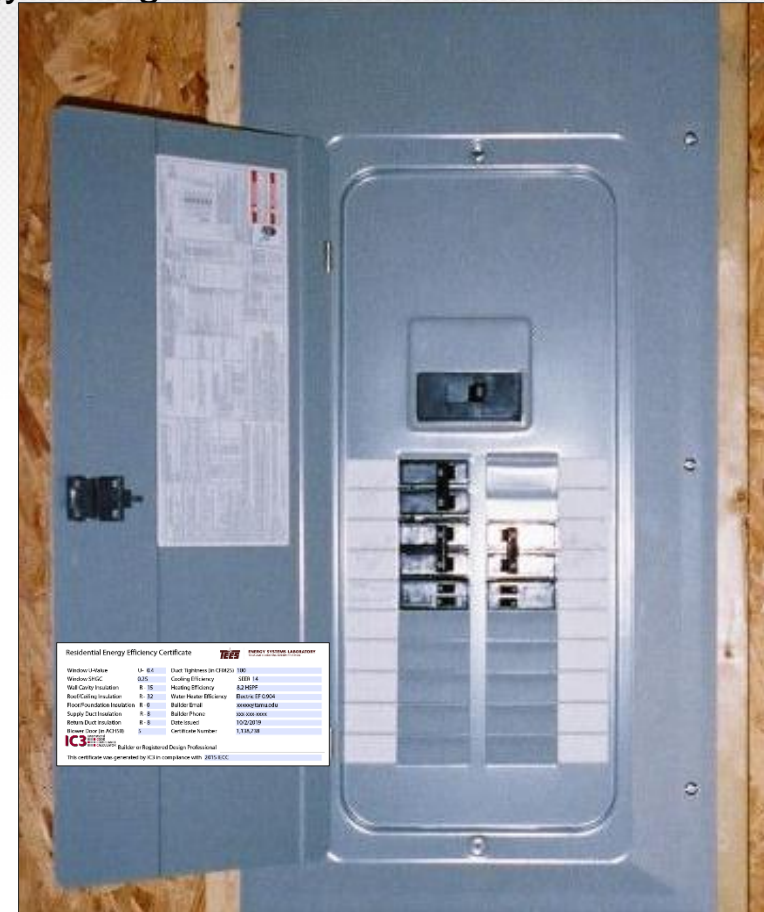
Prints Certificate for Electrical Panel

ENERGY SAVINGS & NO_x EMISSION REDUCTION



ESL Calculates & Reports NO_x Emissions Reductions for: Code-Compliant Construction: Energy savings from new construction

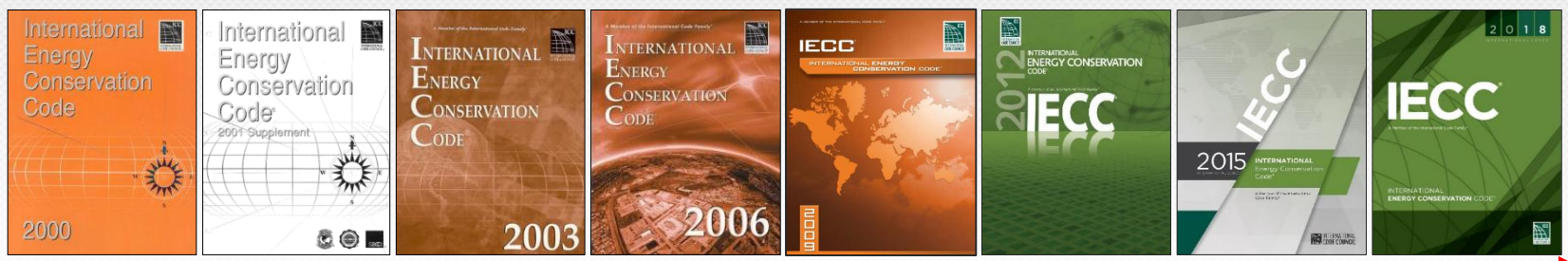
- IC3 Prints Certificate for Posting on Electrical Panel
- Records Certificate in IC3 Registry



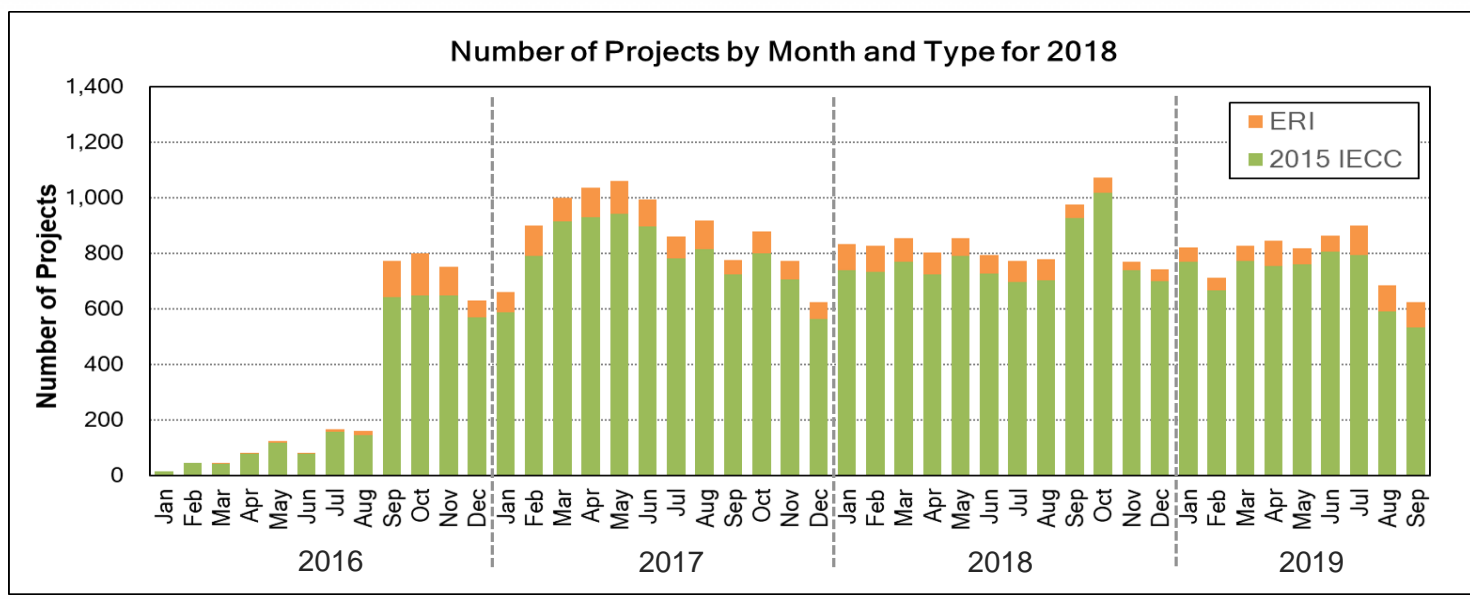
Prints Certificate for Electrical Panel

STATEWIDE SAVINGS FROM CODE COMPLIANCE

How much electricity has been saved from residential code compliance for all single-family housing 2000-2019?



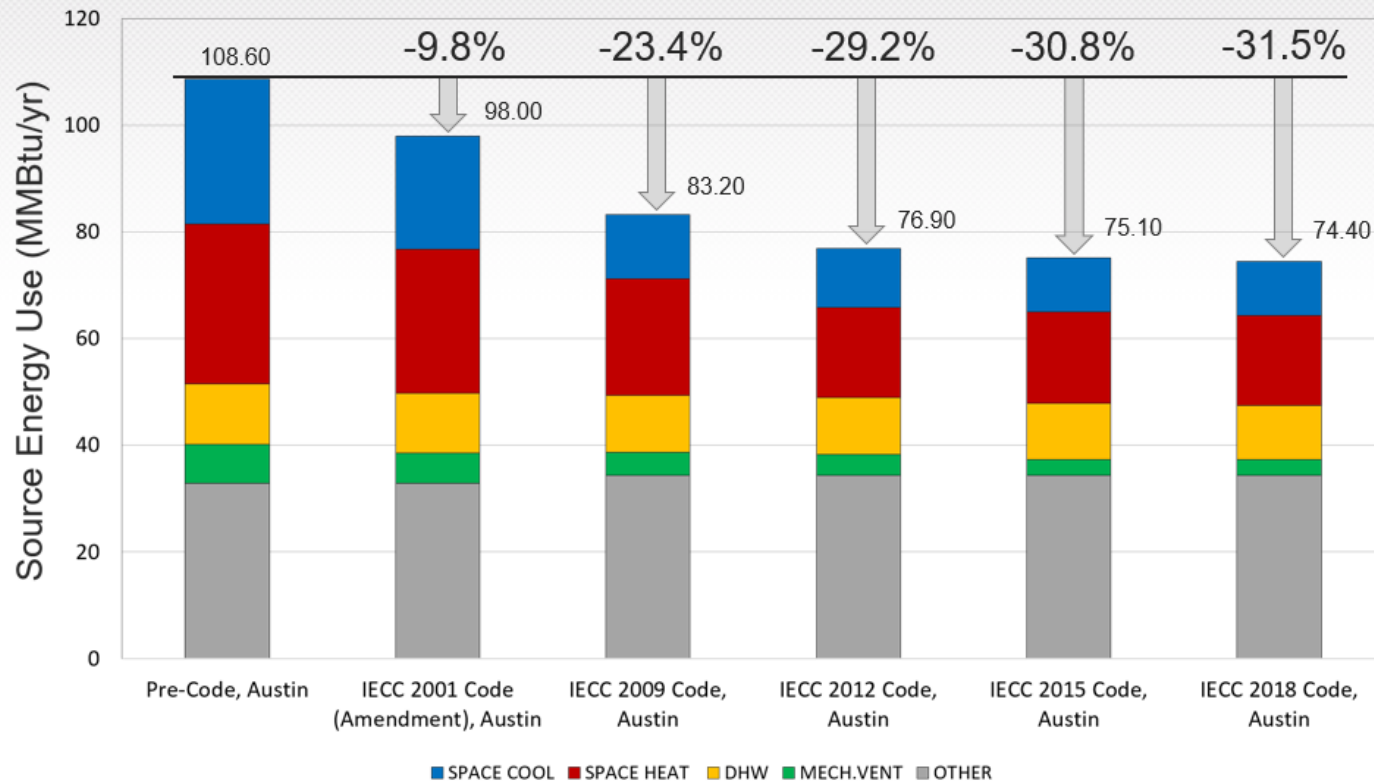
Projects/Certificates
in IC3 Registry



How much residential code compliances have saved in Austin, TX (Climate Zone 2A) from 1999 to 2019?

2,500 ft² SF House

- Wall:** R-11 to R13
- Roof:** R-26 to R-38
- Win Uval:** 1.11 to 0.40
- Win SHGC:** 0.71 to 0.25
- SEER:** 10 to 14
- AFUE:** 0.80 to 0.82
- HSPF:** 6.8 to 8.2
- DHW EF:** 0.86 to 0.95



STATEWIDE SAVINGS FROM CODE COMPLIANCE 2000 – 2018 (ESTIMATED)

Savings (2002 to 2017)

Total: \$6,737 million

Savings (2002 to 2018)

Electricity (Envelope): \$2,352 million (+10.0%)
 Electricity (HVAC Systems): \$2,247 million (+19.5%)
 Demand: \$3,078 million (+13.2%)
 Total: \$7,677 million (+14.0%)

Increased Costs (2002 to 2018)

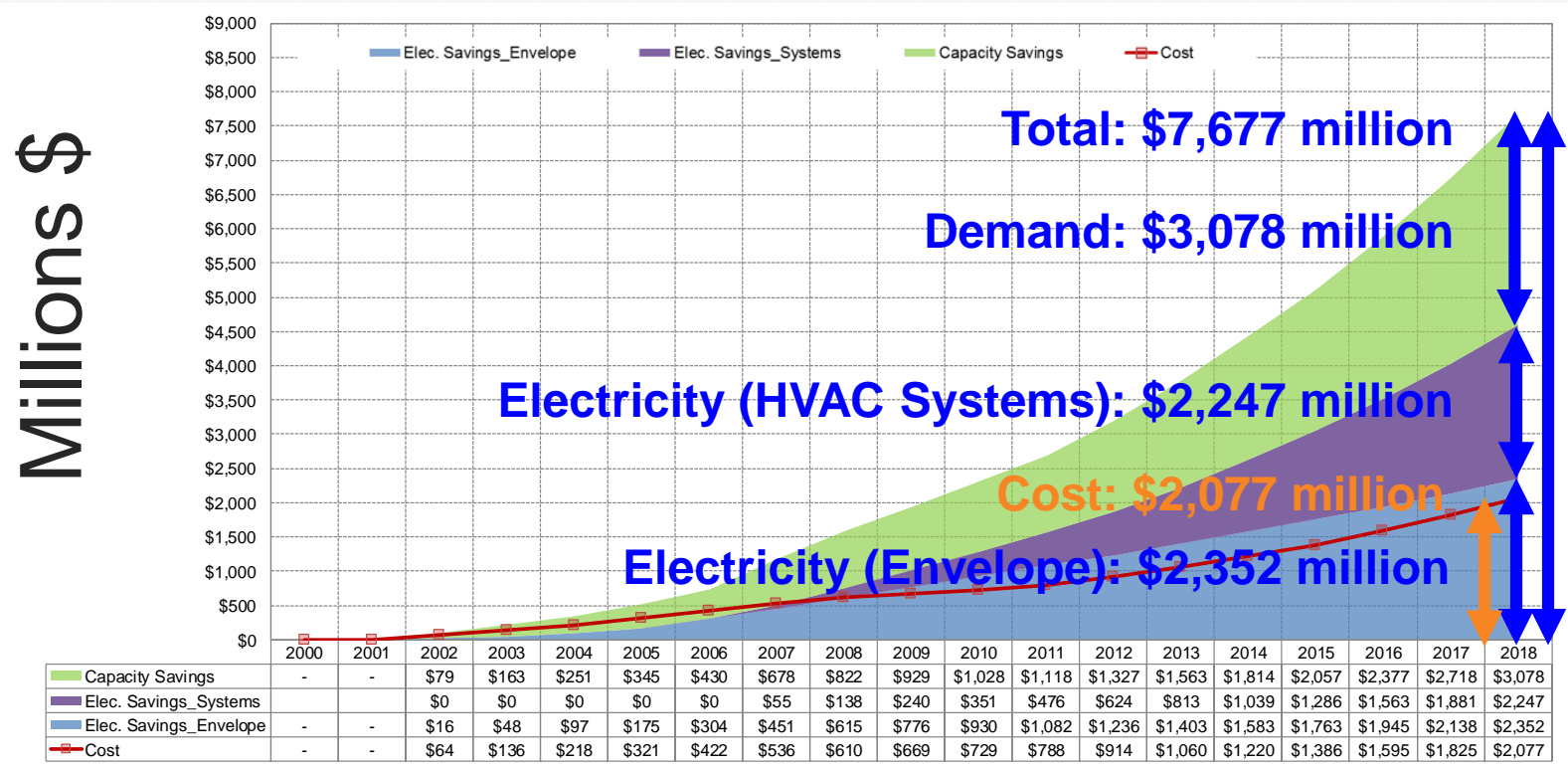
Costs: \$ 2,077 million

NOx Emissions Reduction (2008 to 2018)

82.21 tons NOx / year

Emissions Reduction in 2018

(Equivalent to about 62,500 cars)

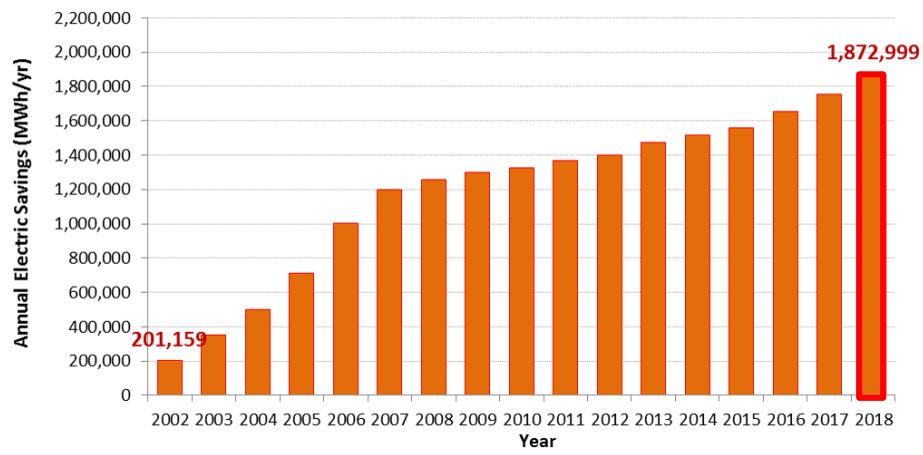


STATEWIDE WATER SAVINGS AT POWER PLANTS

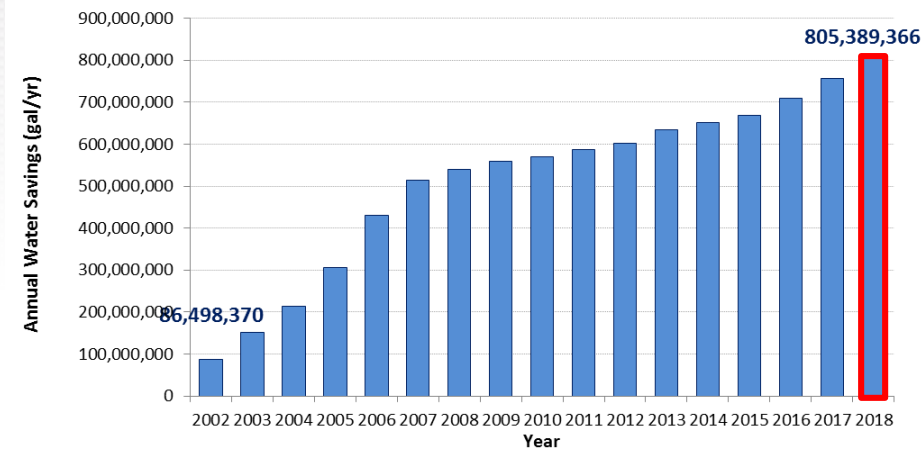
2000 – 2018

Electricity/Water Savings from SF (Code Compliance)

Annual Electric Savings



Annual Water Savings



Seaholm Power Plant, Austin



2018 Total Electricity Savings (MWh/yr)
1,872,999

2018 Total Water Savings	
(gal/yr)	(acre-ft/yr)
805,389,366	2,472

Conversion Factors: 430 gal/MWh
325,851 gal/acre-ft

SAVINGS FROM RENEWABLES

Blue Wing Solar PV Array, San Antonio, TX



Solar PV

2.5 Miles Southwest of Woodville, TX



Biomass

Sunmaxx Solar Thermal, Fort Hood, TX



Solar Thermal

Aspen Power plant in Lufkin, TX



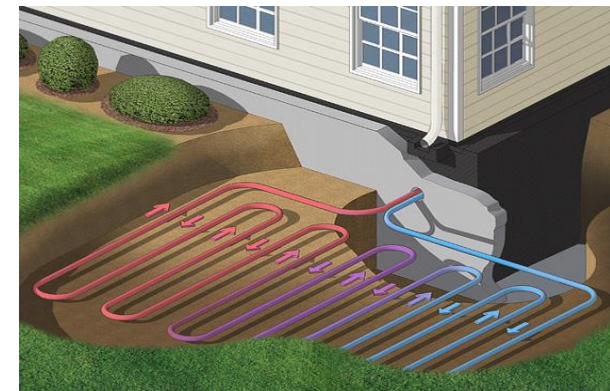
Landfill Gas

Dam at Elephant Butte, El Paso, TX



Hydro

Ground Source Heat Pump



Geothermal

SAVINGS FROM RENEWABLES

Blue Wing Solar PV Array, San Antonio, TX



Sol

2.5 Miles Southwes



Biomass

Sunmaxx Solar Thermal, Fort Hood, TX



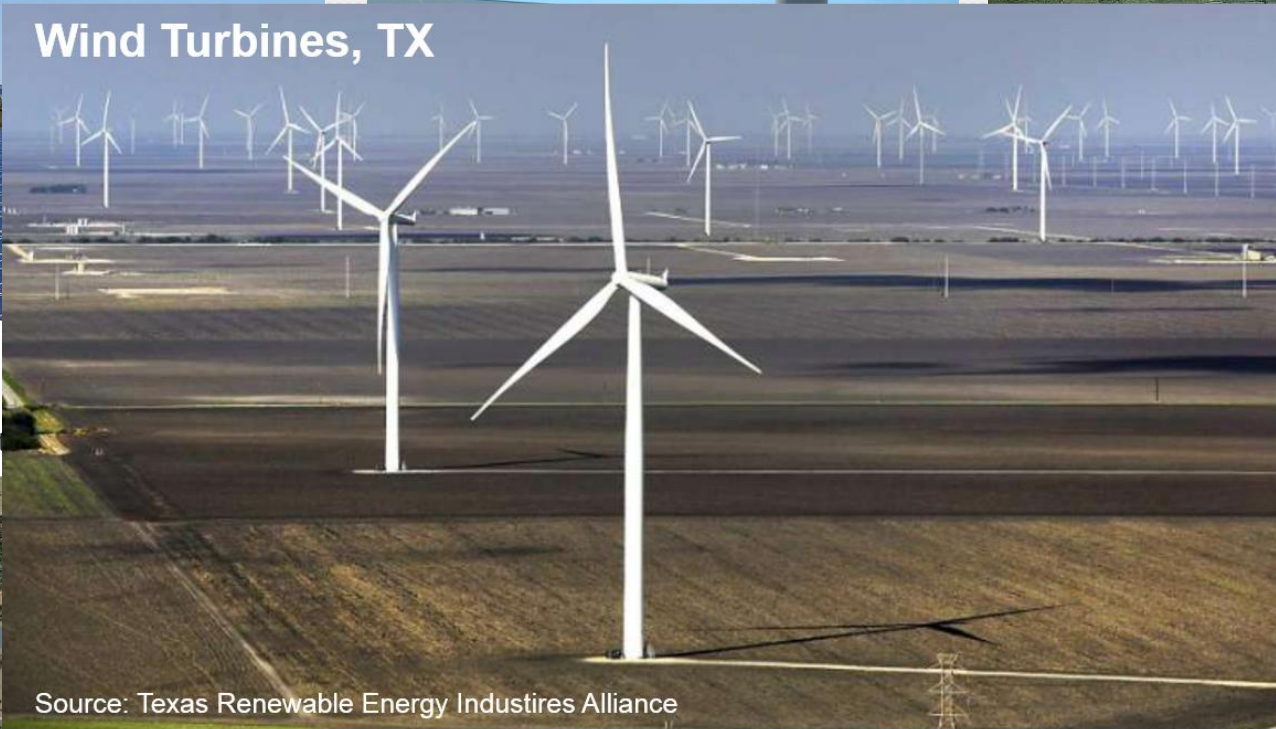
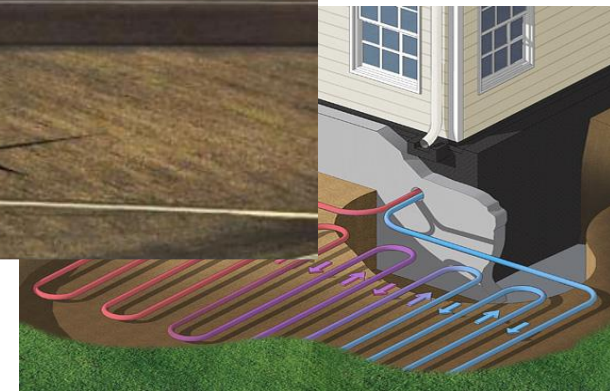
Landfill Gas



Dam at Elephant Butte, El Paso, TX

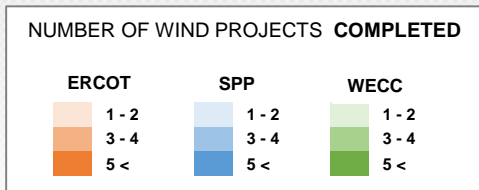


Geothermal

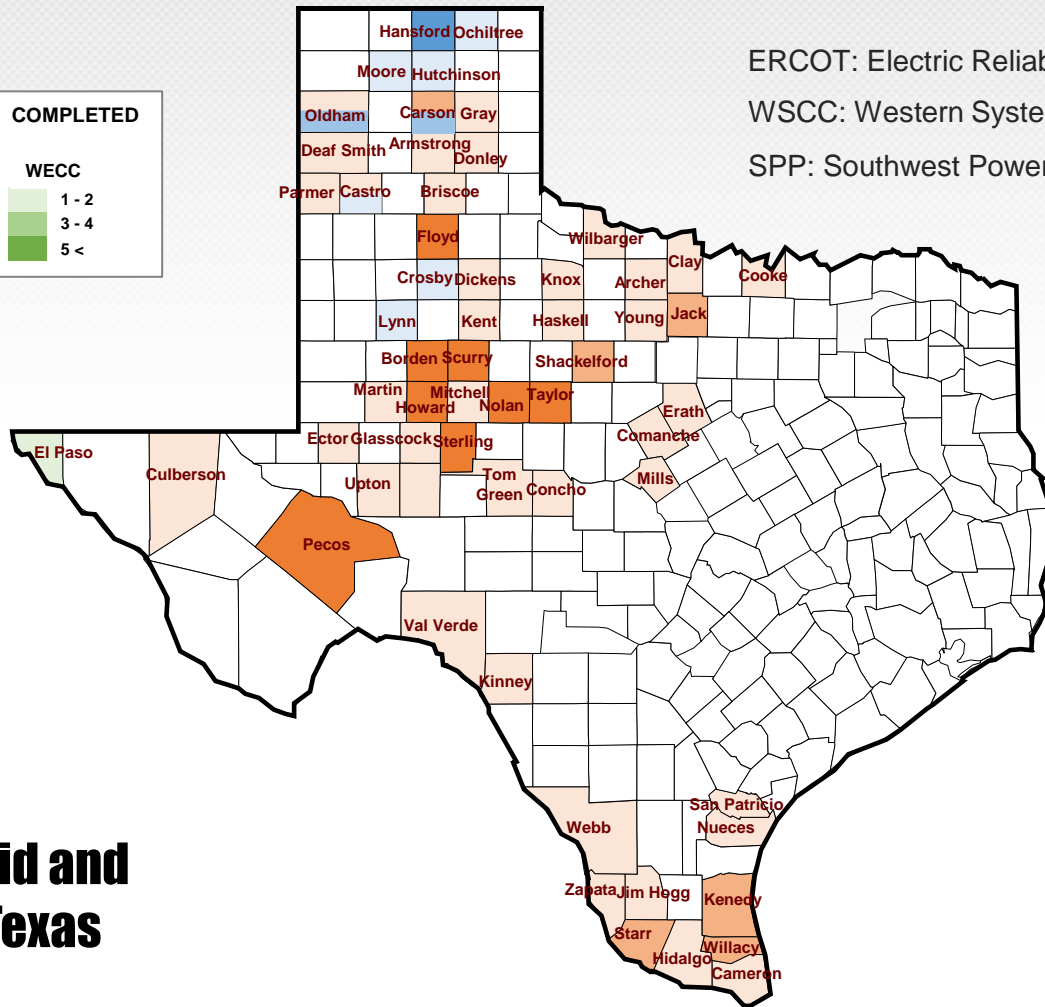


WIND PROJECTS IN TEXAS (2018)

Completed Wind Projects in Texas, as of Dec. 2018



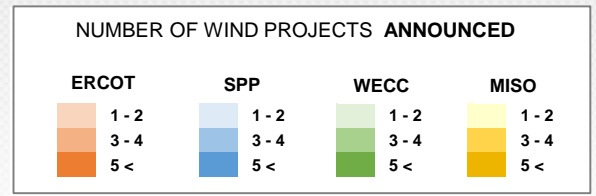
ERCOT: Electric Reliability Council of Texas
WSCC: Western Systems Coordinating Council
SPP: Southwest Power Pool



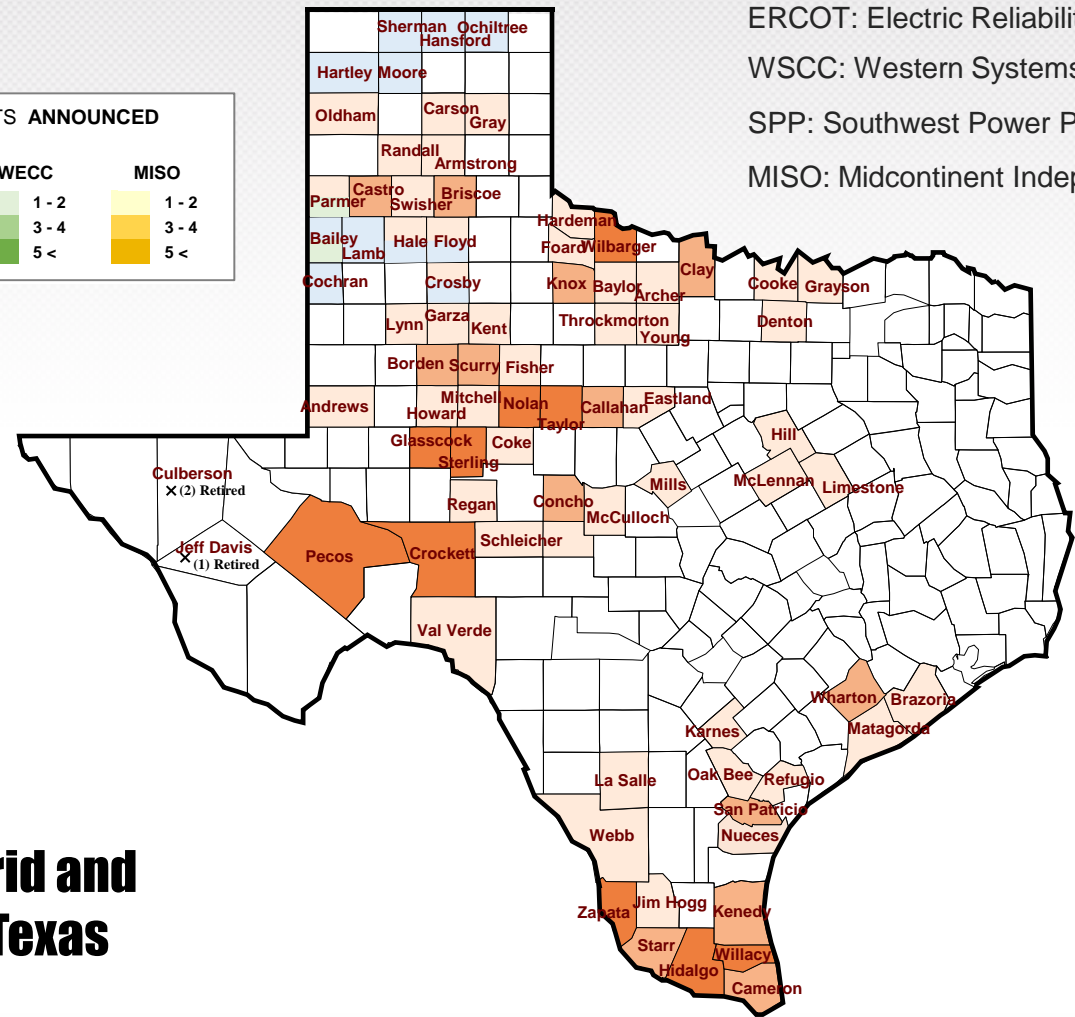
**ERCOT Power Grid and
Wind Farms in Texas**

WIND PROJECTS IN TEXAS (2018)

Announced and Retired Wind Projects in Texas, as of Dec. 2018



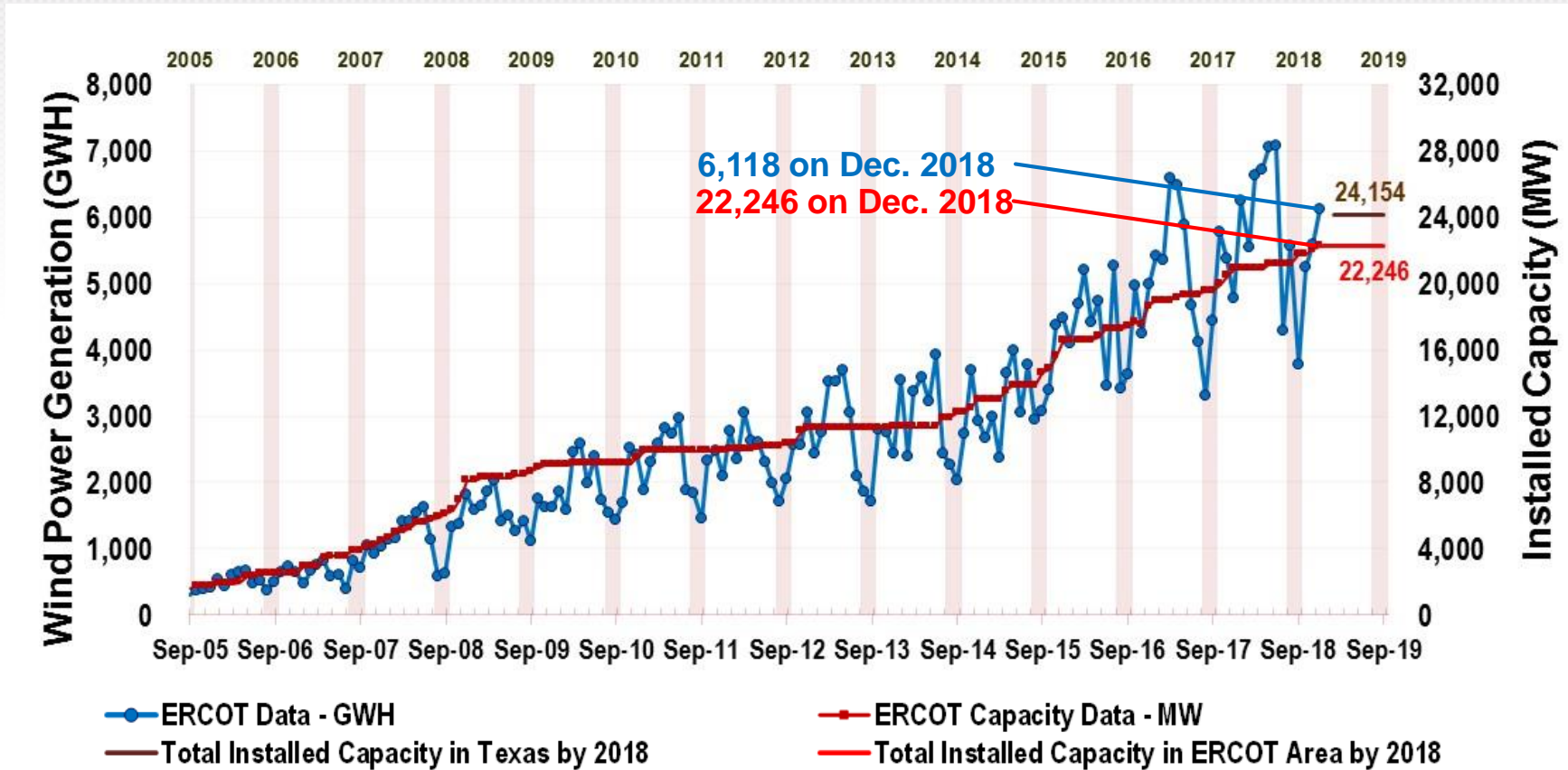
ERCOT: Electric Reliability Council of Texas
 WSCC: Western Systems Coordinating Council
 SPP: Southwest Power Pool
 MISO: Midcontinent Independent System Operator



ERCOT Power Grid and Wind Farms in Texas

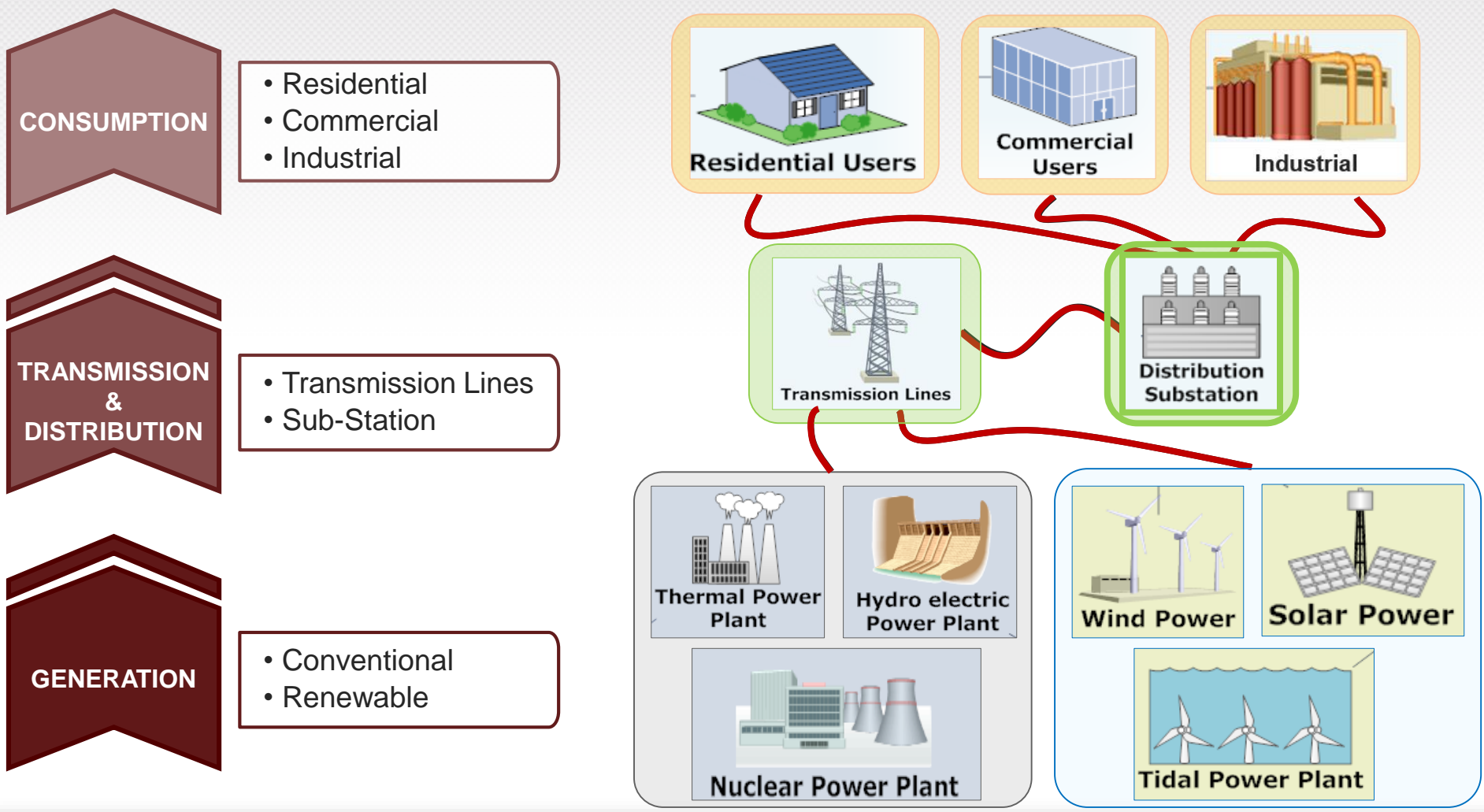
WIND PROJECTS IN TEXAS (2018)

ERCOT Capacity 22,246 MW Total Capacity 24,154 MW Total Wind Power 69,898 GWh



NOx REDUCTIONS USING eGRID

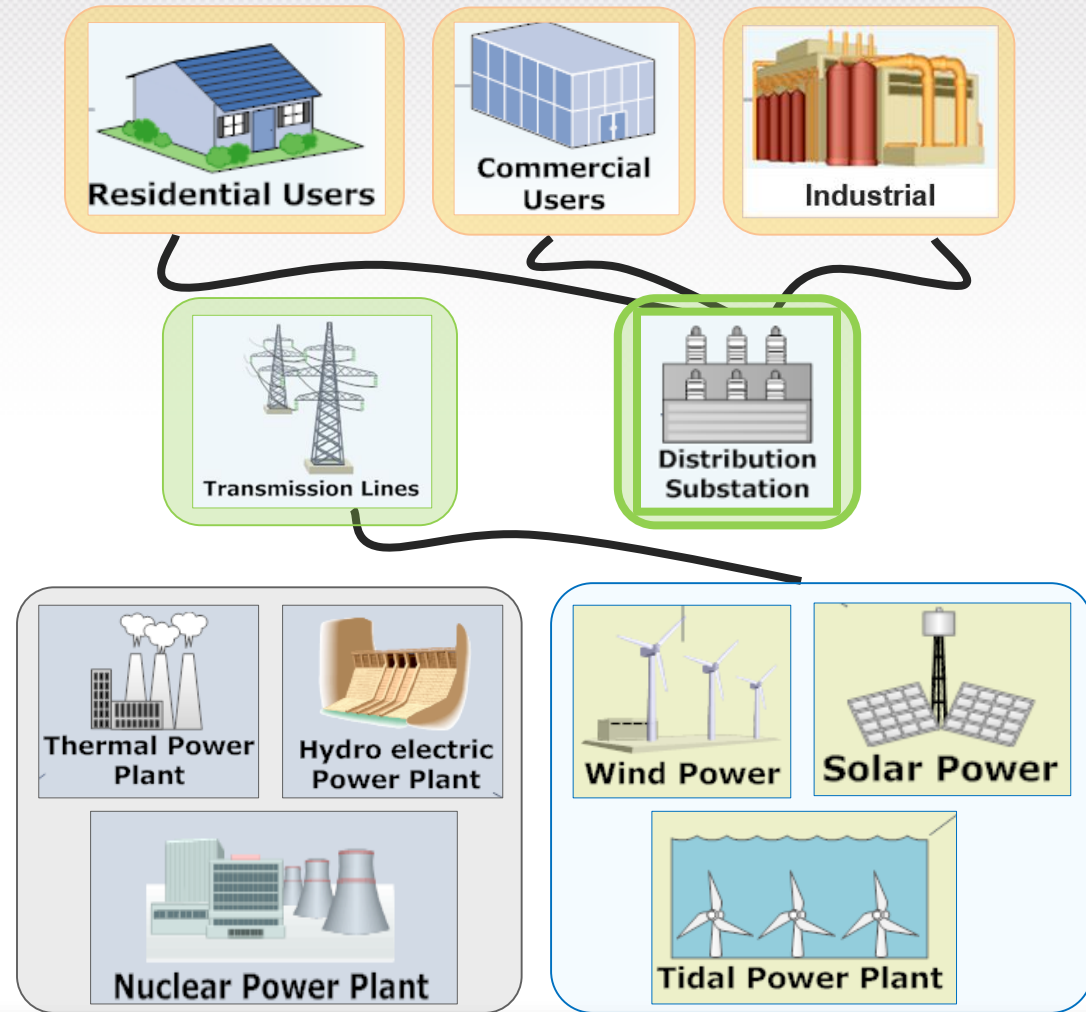
NOx emissions reductions calculation from electricity savings



NOx REDUCTIONS USING eGRID

NOx emissions reductions calculation from electricity savings

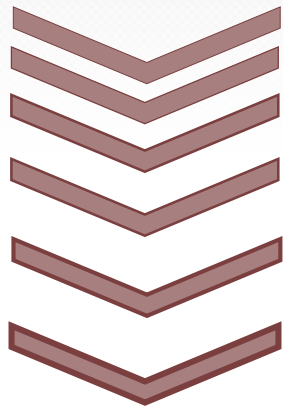
Energy Savings from EE/RE Programs



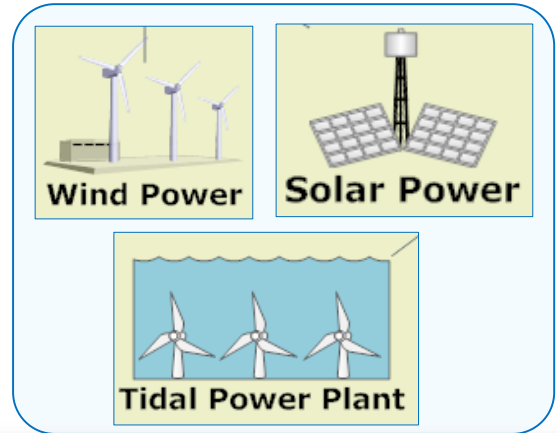
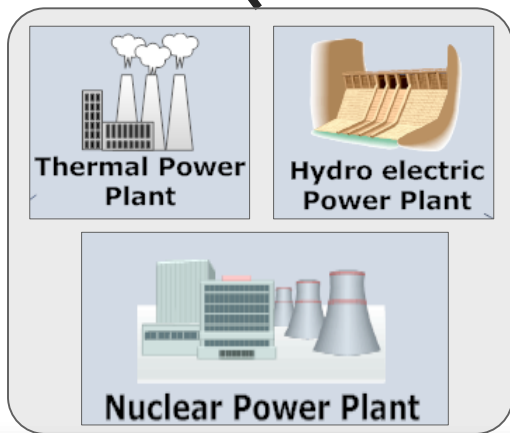
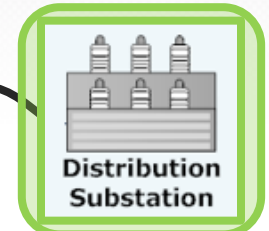
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NOx emissions reductions calculation from electricity savings

Energy Savings from EE/RE Programs



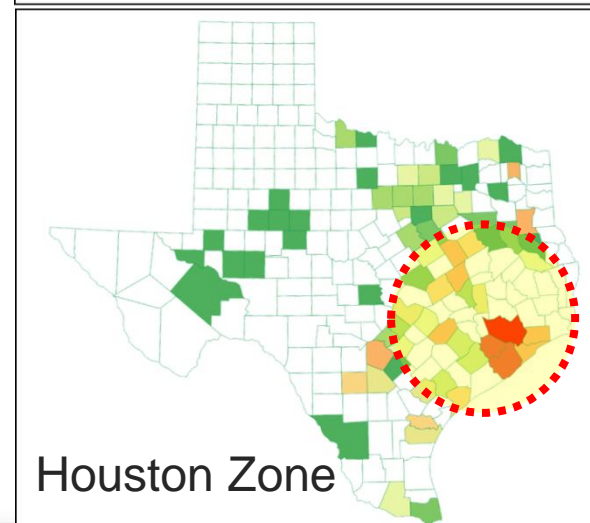
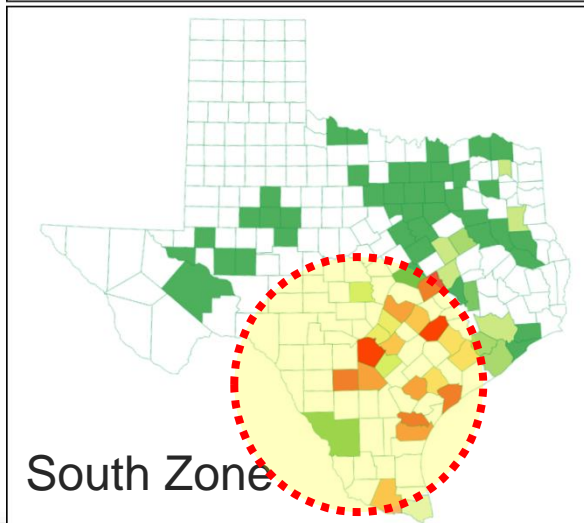
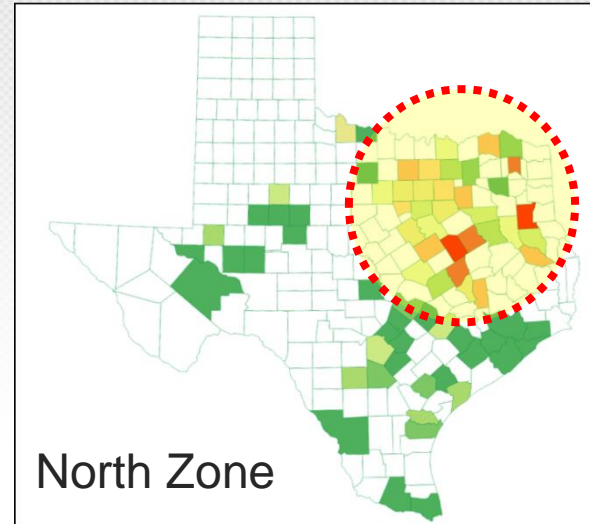
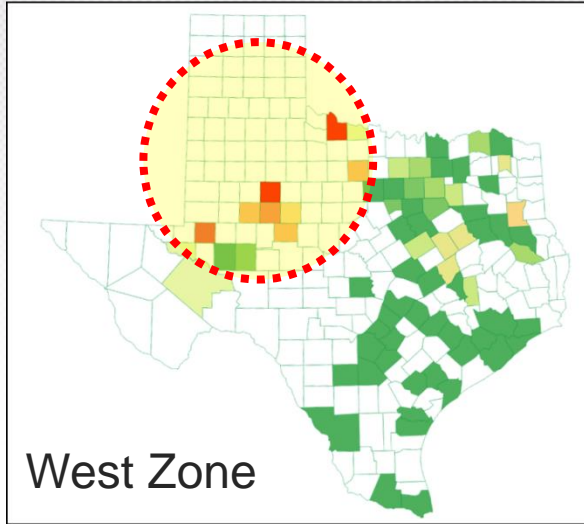
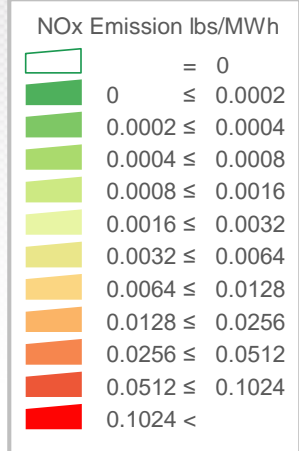
Energy Production & Emissions Reductions



New 2016 eGRID for NOx Emissions

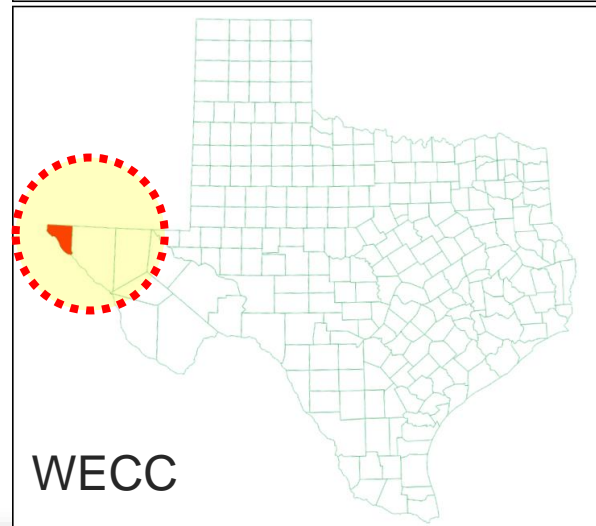
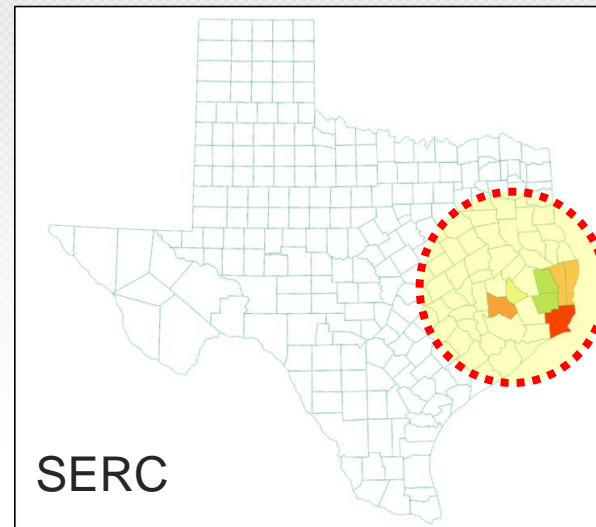
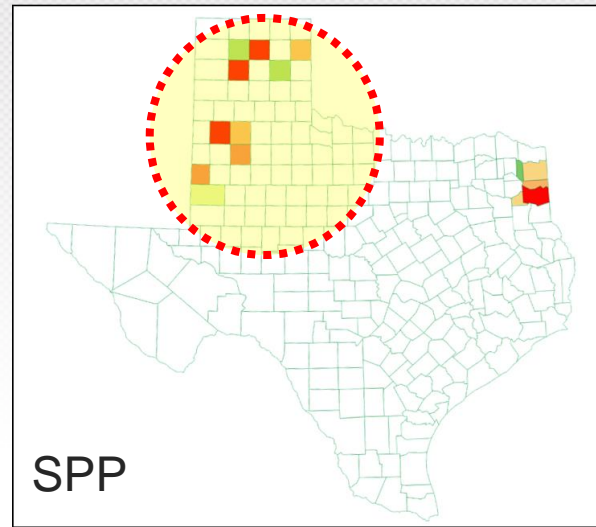
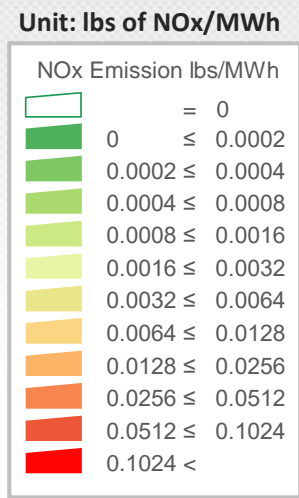
New 2016 eGRID (Annual) for NOx Emissions – ERCOT Region

Unit: lbs of NOx/MWh



New 2016 eGRID for NOx Emissions

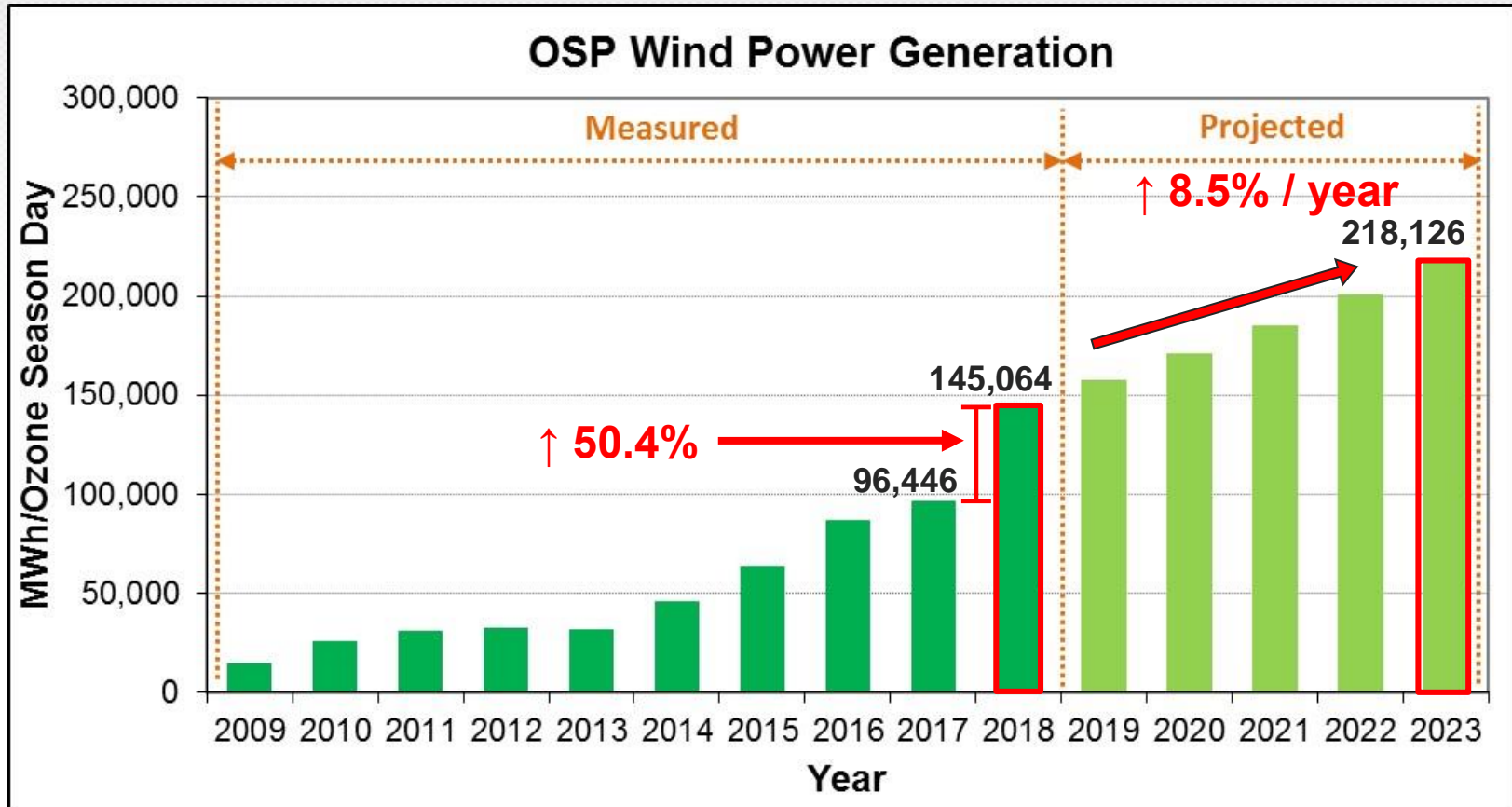
New 2016 eGRID (Annual) for NOx Emissions - New Regions



- ERCOT:** Electric Reliability Council of Texas
- SPP:** Southwest Power Pool
- SERC:** Southeastern Electric Reliability Council
- WECC:** Western Electricity Coordinating Council

NOx REDUCTIONS FROM WIND POWER

OSP Power Generation and NOx Emissions Reductions (2008 base year)

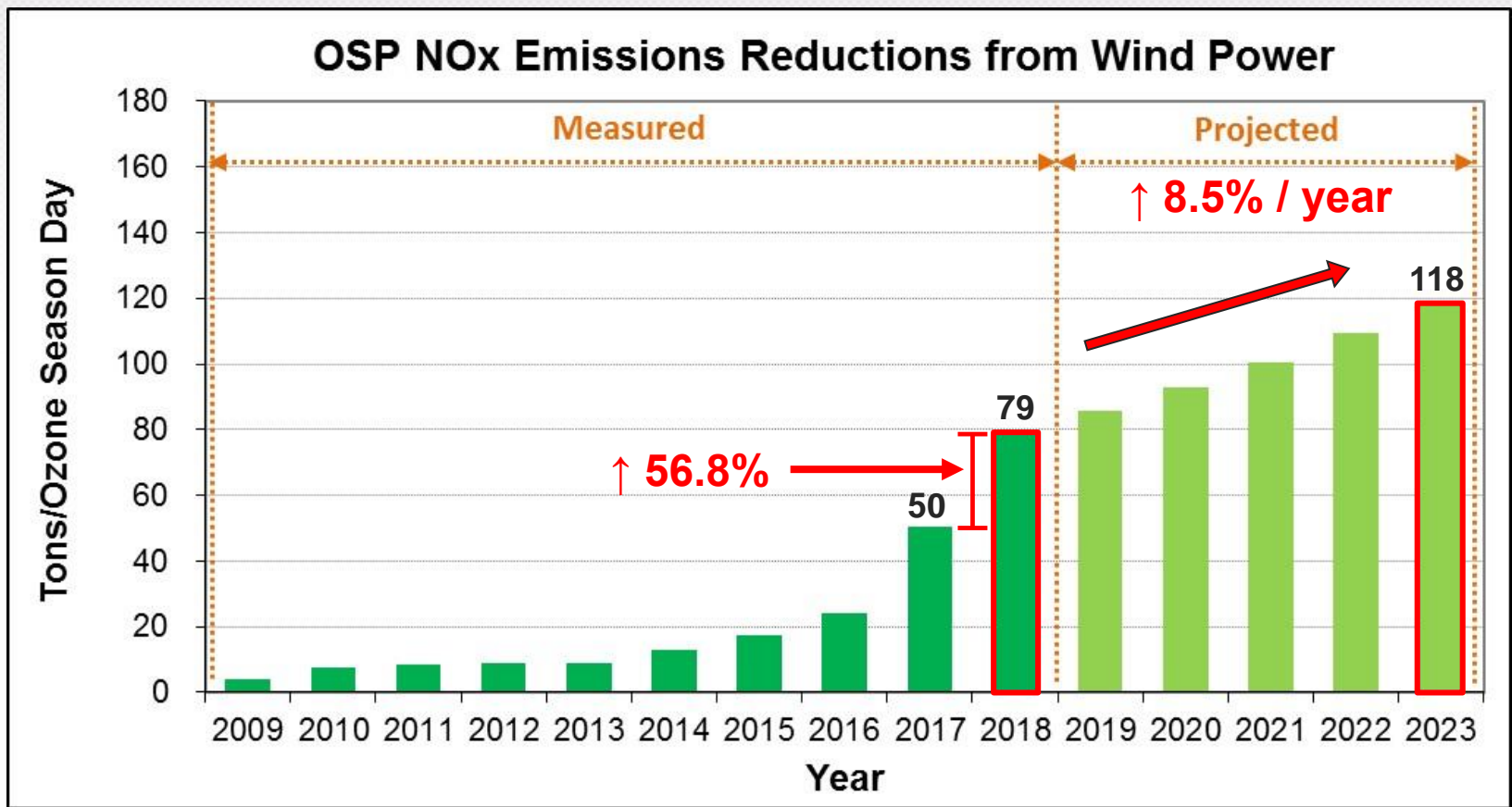


Source: 15-min Wind Generation Data from ERCOT

OSP: The Ozone Season Period (OSP) was changed from the period of Jul 15 - Sep 15 to the period of May 1 - Sep 30

NOx REDUCTIONS FROM WIND POWER

OSP Power Generation and NOx Emissions Reductions (2008 base year)

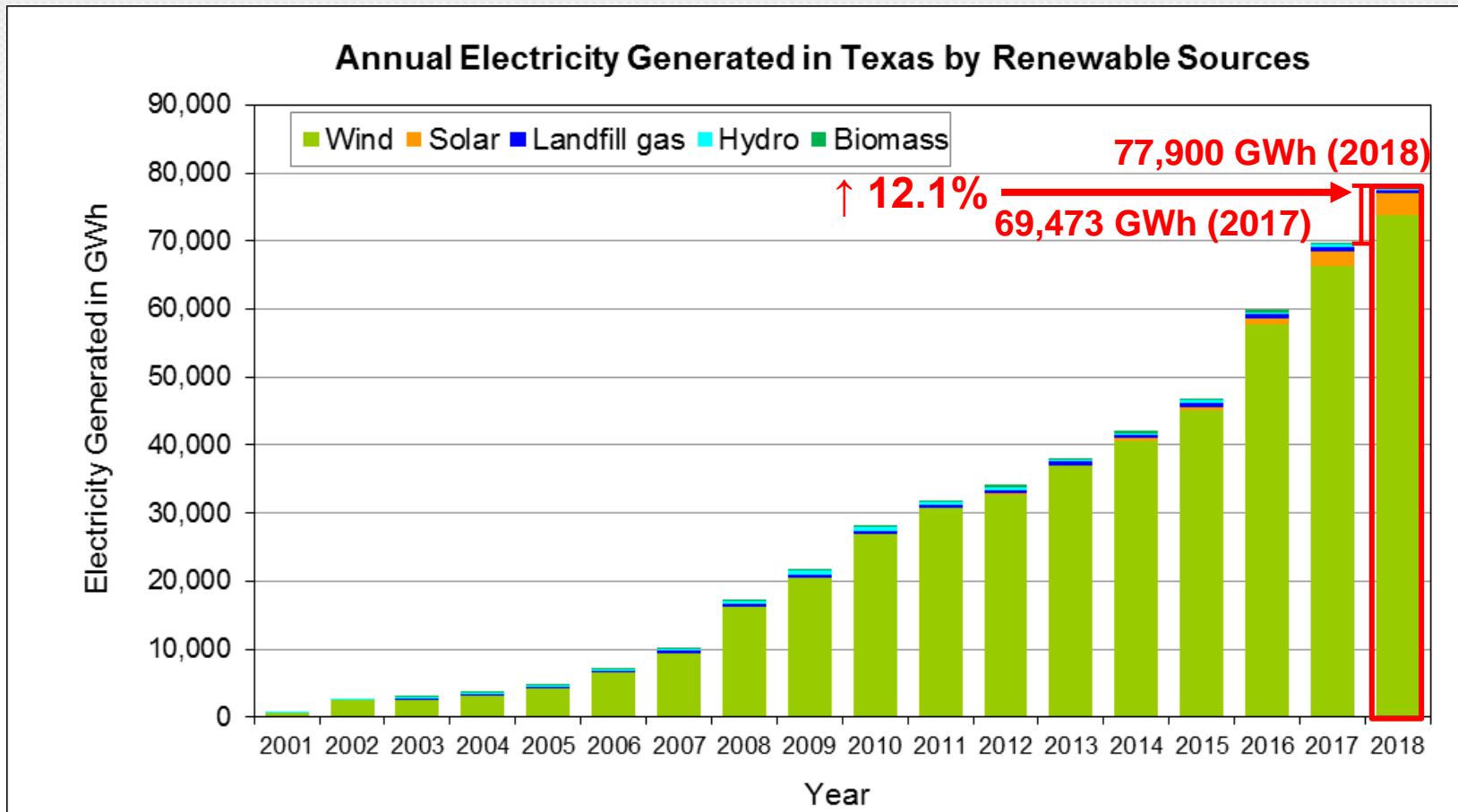


Source: 15-min Wind Generation Data from ERCOT

SAVINGS FROM OTHER RENEWABLES (2001-2018)

Renewables: Biomass, Hydro, Landfill Gas, Solar, Wind

✓ Wind energy is the largest portion



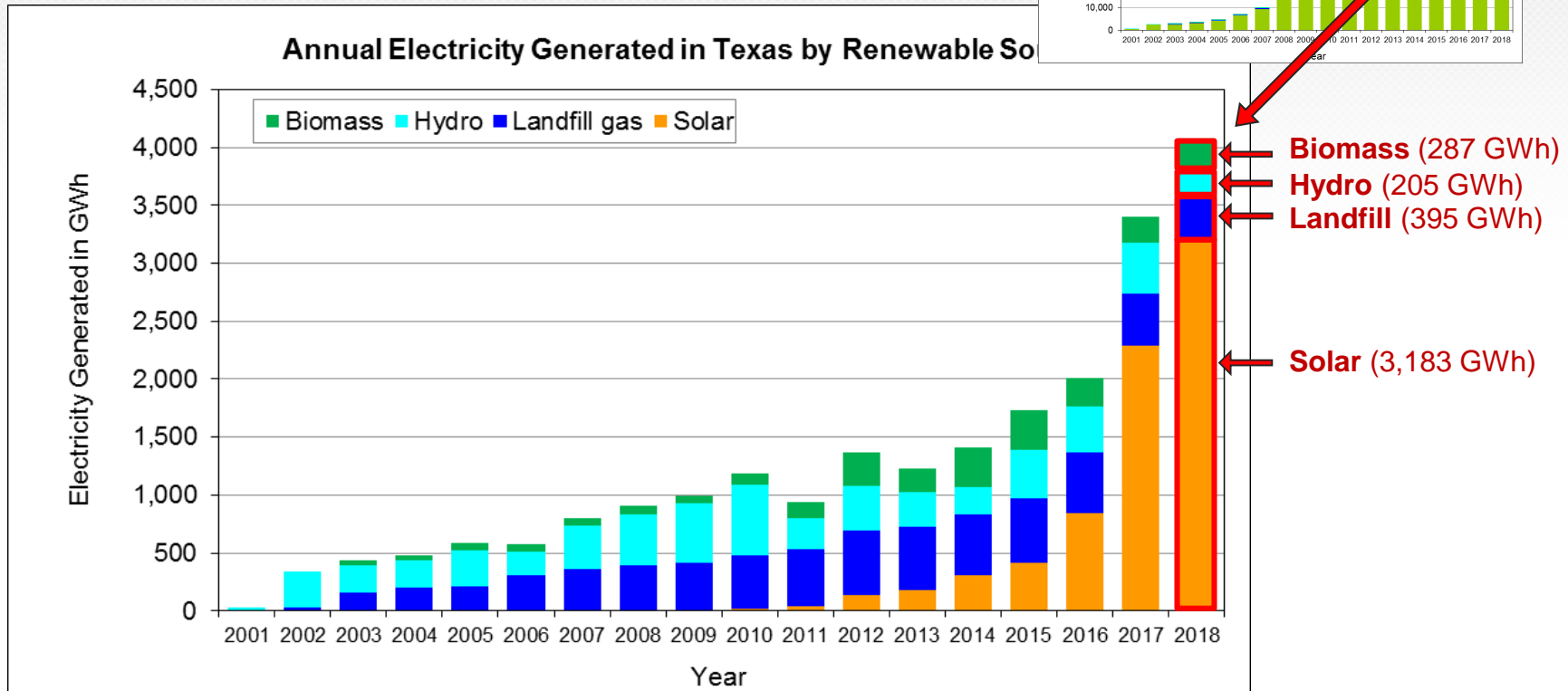
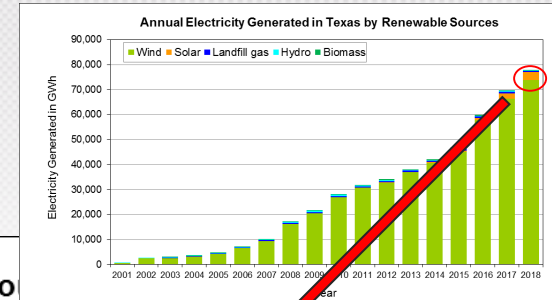
Source: Renewable Generation Data from ERCOT-REC (Renewable Energy Credit)

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Excluding Wind

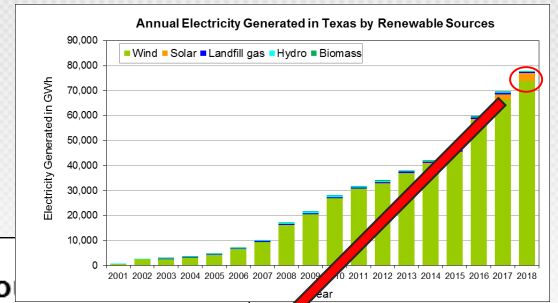


Source: Renewable Generation Data from ERCOT-REC (Renewable Energy Credit)

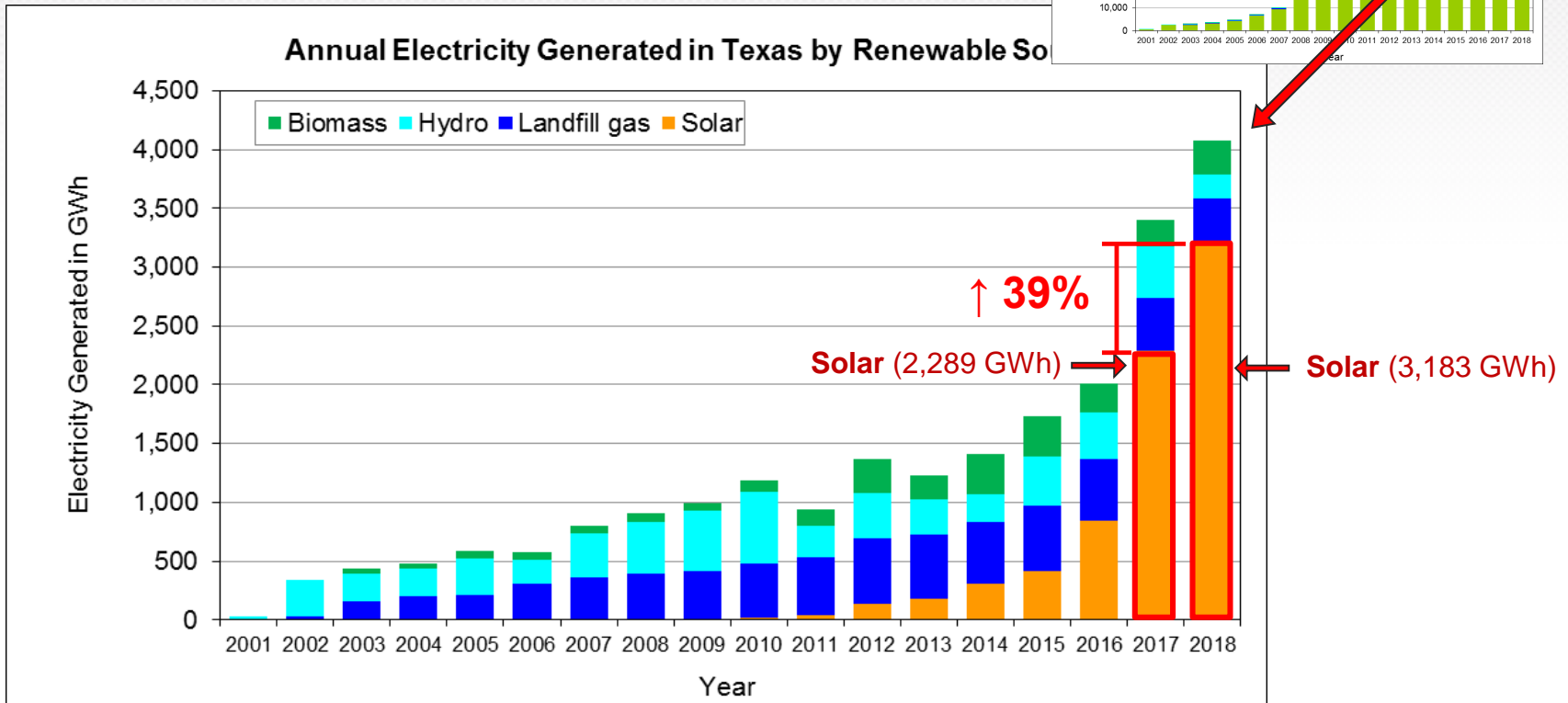
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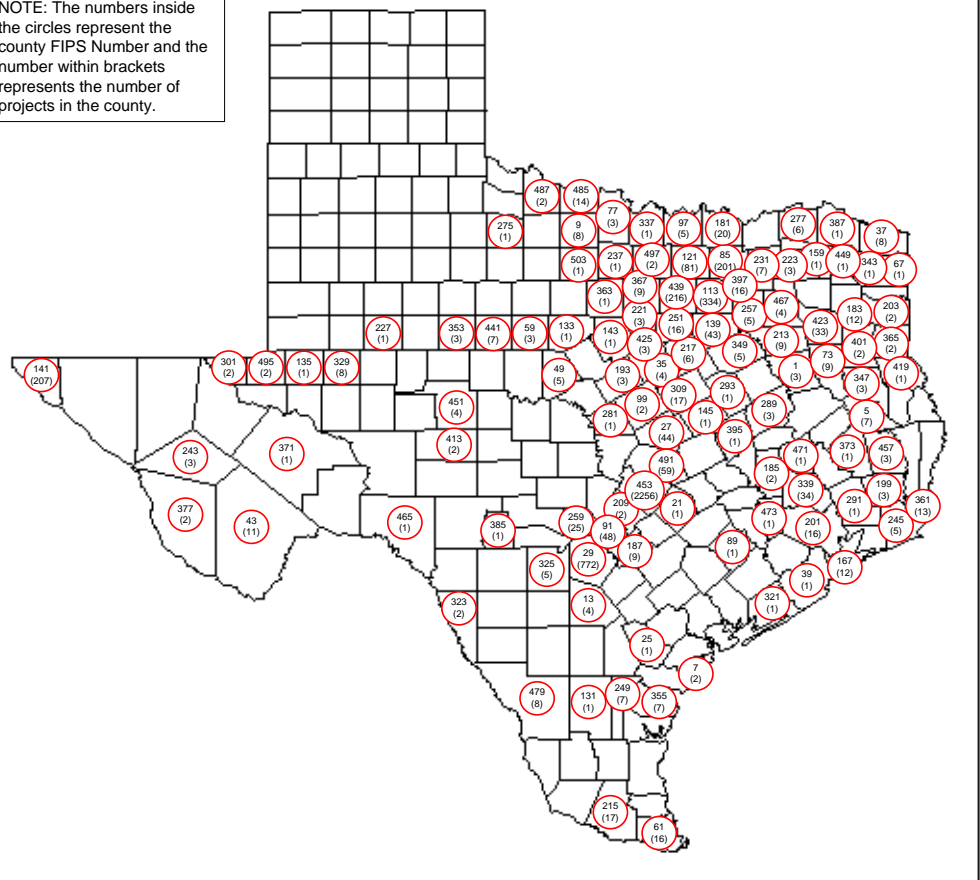


Source: Renewable Generation Data from ERCOT-REC (Renewable Energy Credit)

RENEWABLE PROJECTS IN TEXAS (2018)

Solar PV

NOTE: The numbers inside the circles represent the county FIPS Number and the number within brackets represents the number of projects in the county.



Renewables*:

Solar PV - non utility scale
(4,794 projects) **+8 projects**

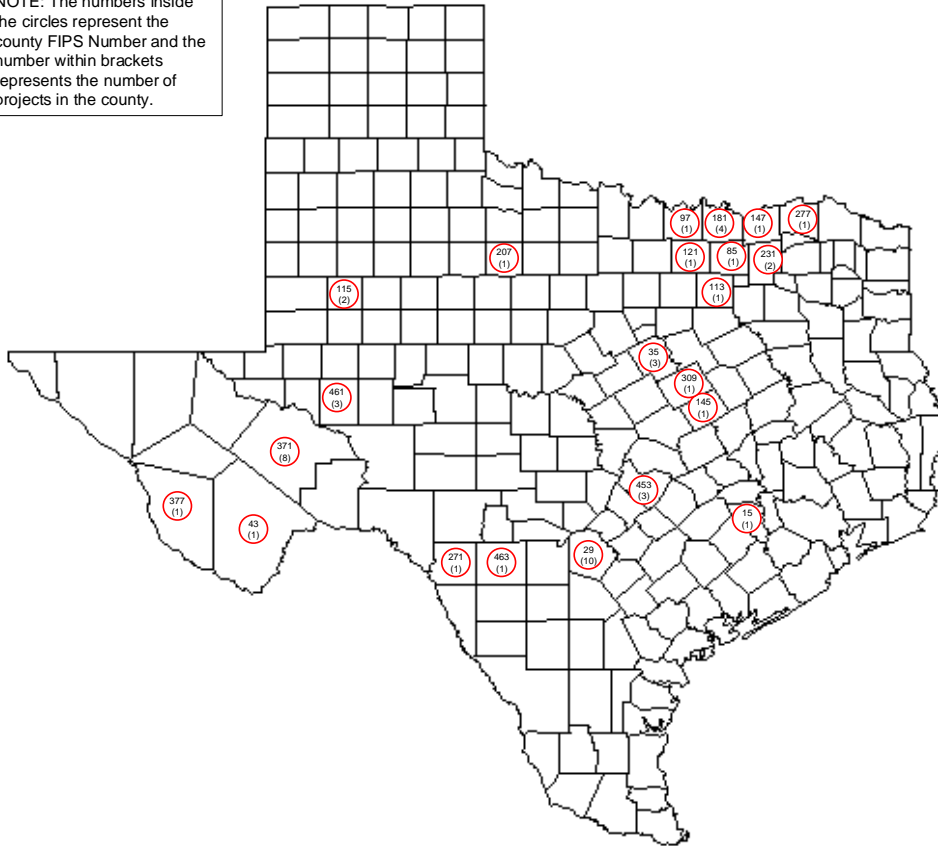
Solar Pv - non utility scale



RENEWABLE PROJECTS IN TEXAS (2018)

Solar PV

NOTE: The numbers inside the circles represent the county FIPS Number and the number within brackets represents the number of projects in the county.



Renewables*:

Solar PV - non utility scale
(4,794 projects) **+8 projects**

Solar PV- utility scale
(49 projects) **+18 projects**

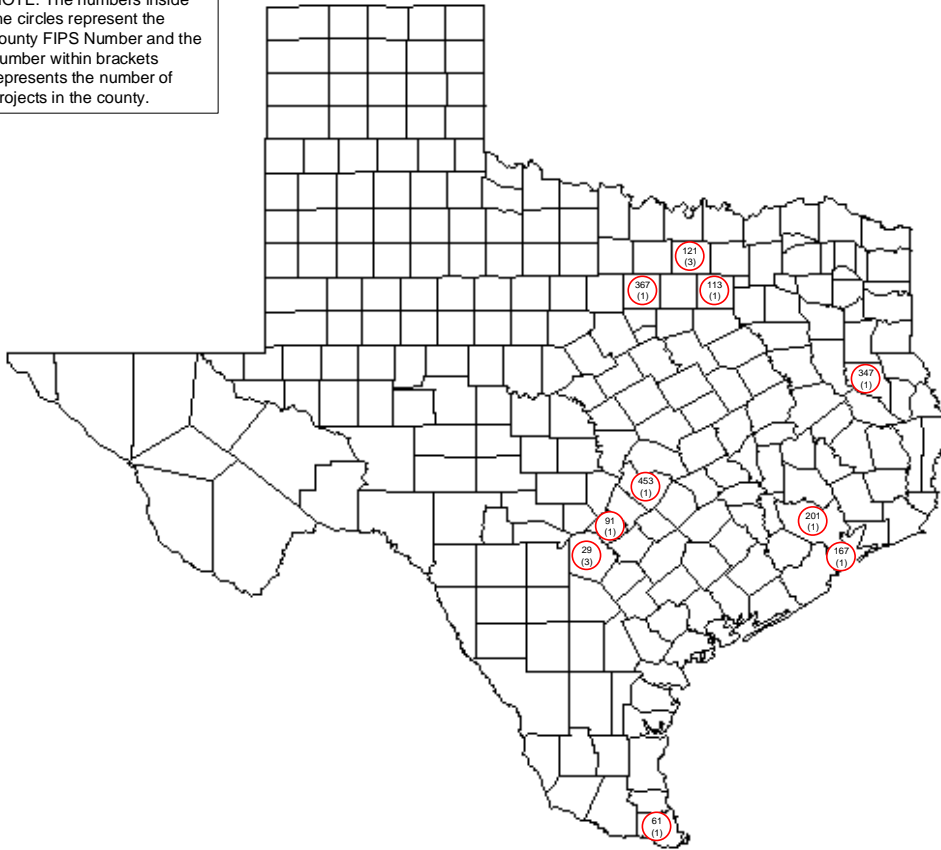
Blue Wing Solar PV Array ,San Antonio



RENEWABLE PROJECTS IN TEXAS (2018)

Biomass

NOTE: The numbers inside the circles represent the county FIPS Number and the number within brackets represents the number of projects in the county.



Renewables*:

Solar PV - non utility scale
(4,794 projects) **+8 projects**

Solar PV- utility scale
(49 projects) **+18 projects**

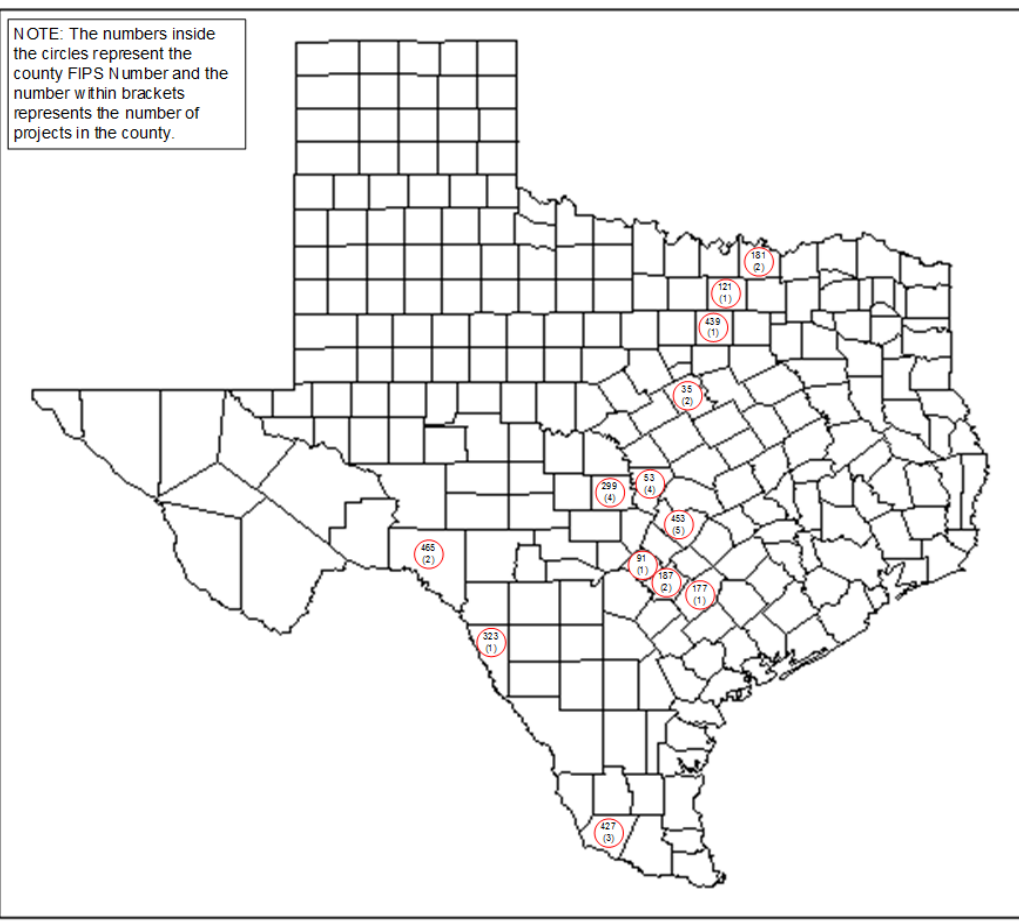
Biomass (14 projects)

2.5 Miles Southwest of Woodville, TX



RENEWABLE PROJECTS IN TEXAS (2018)

Hydro



Renewables*:

Solar PV - non utility scale
(4,794 projects) **+8 projects**

Solar PV- utility scale
(49 projects) **+18 projects**

Biomass (14 projects)

Hydro (29 projects)

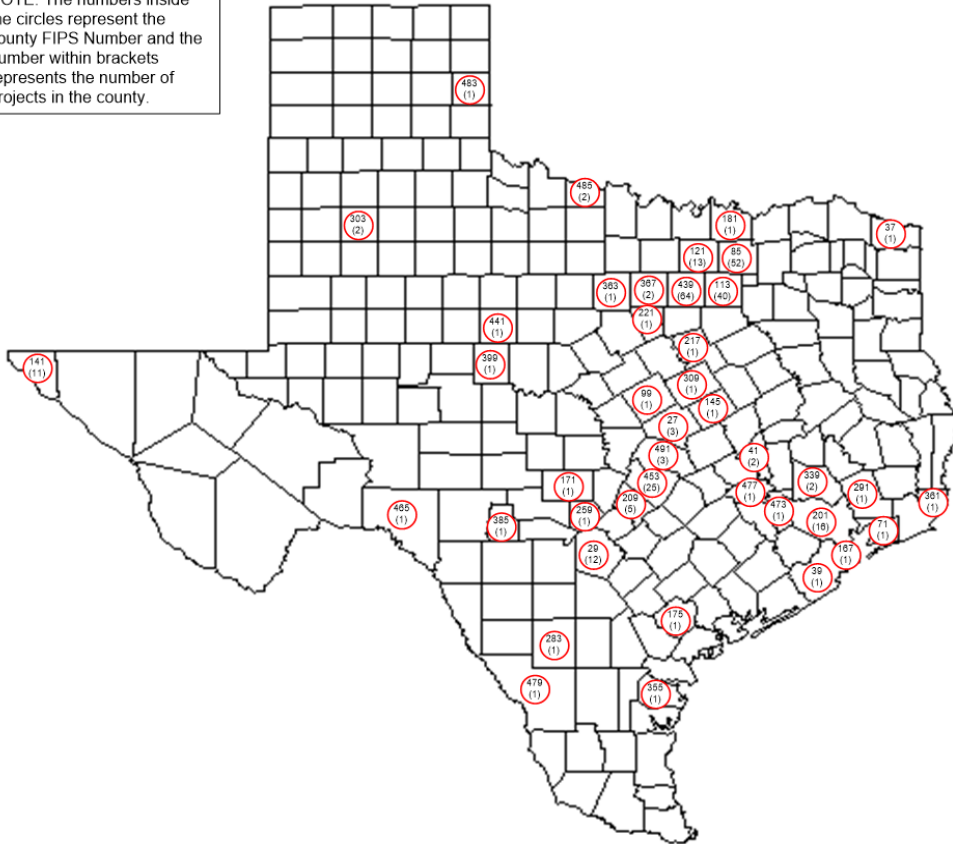
Dam at Elephant Butte, El Paso, TX



RENEWABLE PROJECTS IN TEXAS (2018)

Geothermal

NOTE: The numbers inside the circles represent the county FIPS Number and the number within brackets represents the number of projects in the county.



Renewables*:

Solar PV - non utility scale
(4,794 projects) **+8 projects**

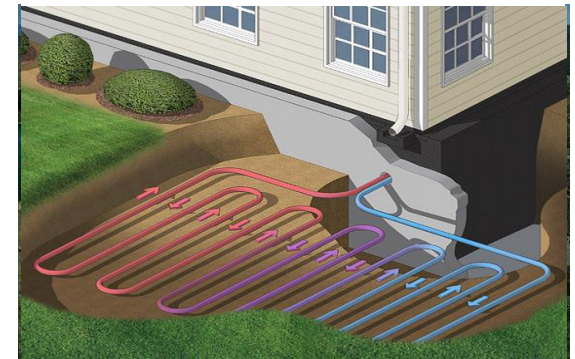
Solar PV- utility scale
(49 projects) **+18 projects**

Biomass (14 projects)

Hydro (29 projects)

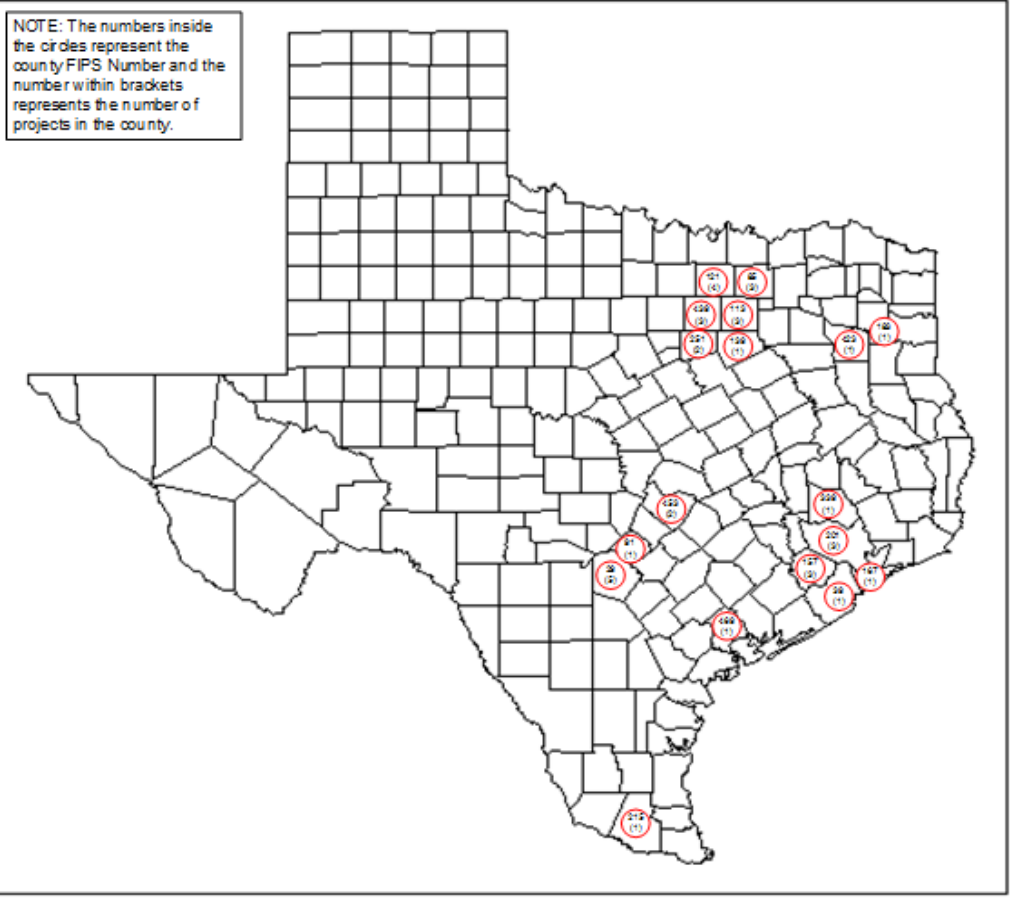
Geothermal (286 projects)

Ground Source Heat Pump



RENEWABLE PROJECTS IN TEXAS (2018)

Landfill Gas



Renewables*:

- Solar PV - non utility scale** (4,794 projects) **+8 projects**
- Solar PV- utility scale** (49 projects) **+18 projects**
- Biomass** (14 projects)
- Hydro** (29 projects)
- Geothermal** (286 projects)
- Landfill Gas** (37 projects)

Aspen Power plant in Lufkin, TX

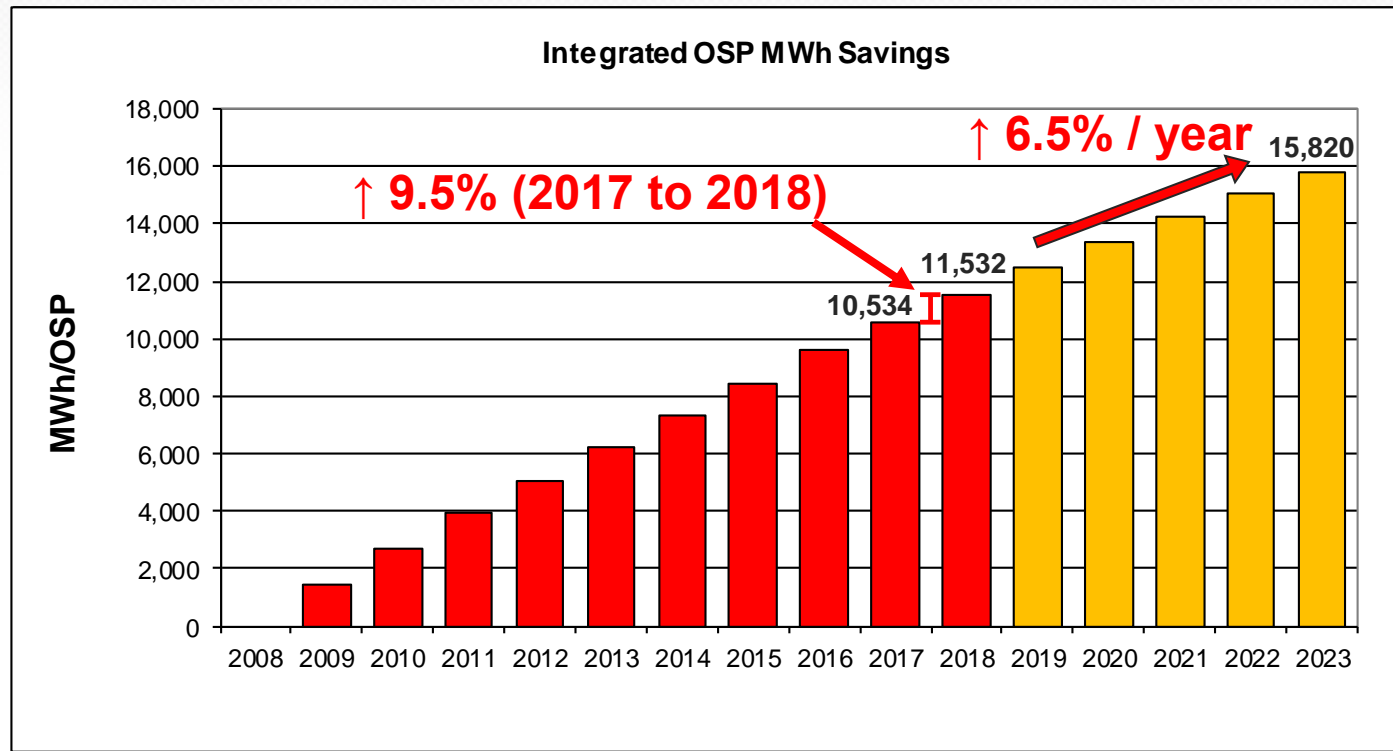


* Included renewable projects if their information/data are available

ENERGY SAVINGS FROM PUC SB7

PUC SB7 Savings and Projections

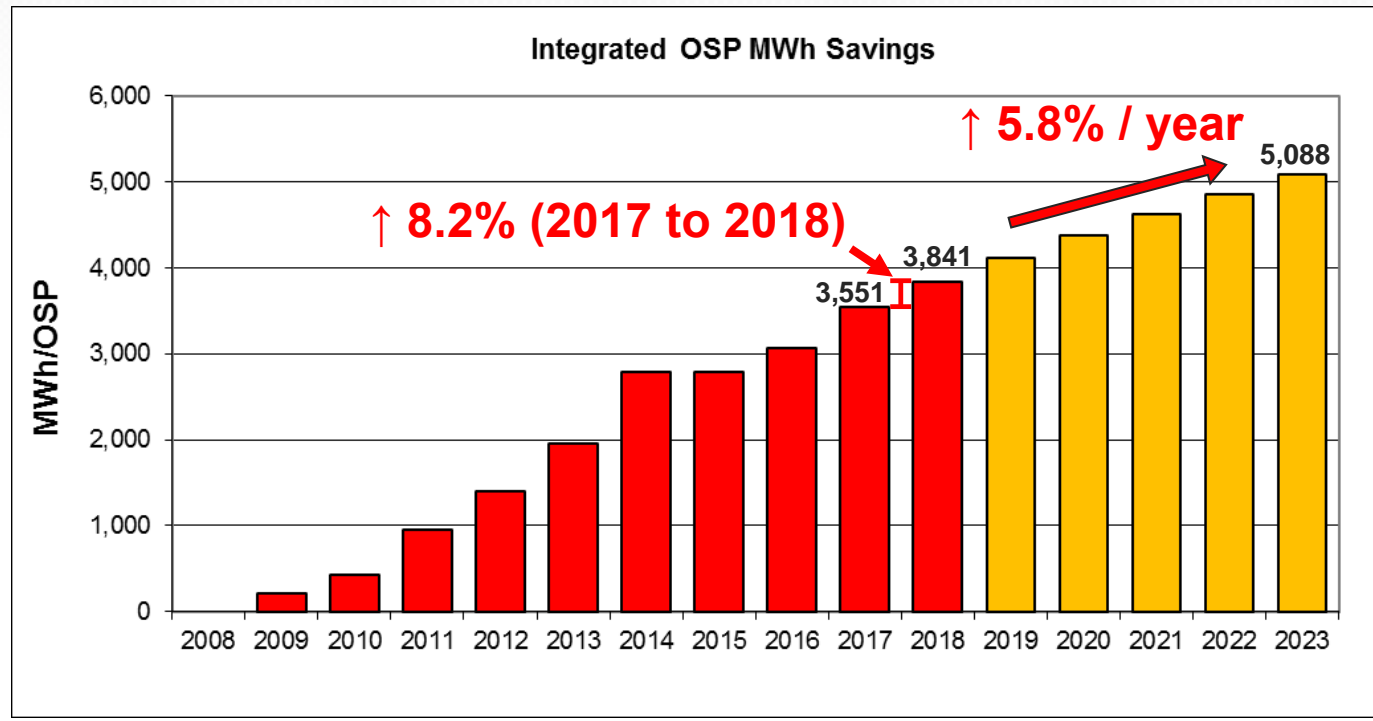
- The Public Utility Commission of Texas (PUC) Senate Bill 7 program includes their incentive and rebates programs managed by the different Utilities for Texas.
- These include the Residential Energy Efficiency Programs (REEP) as well as the Commercial & Industrial Standard Offer Programs.



ENERGY SAVINGS FROM SECO

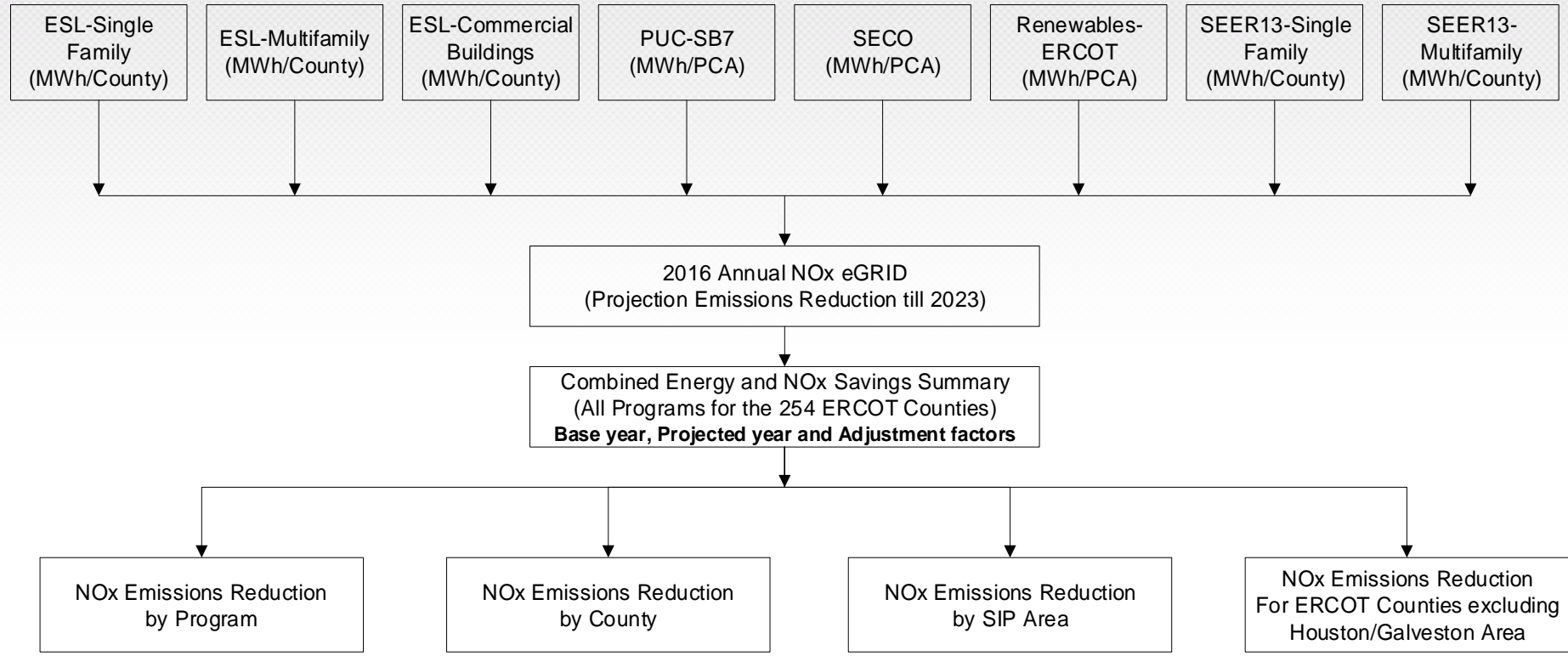
SECO Savings and Projections

- The Texas State Energy Conservation Office (SECO) funds energy-efficiency programs directed towards school districts, government agencies, city and county governments, private industries and residential energy consumers.
- The annual electricity savings are obtained from SECO's energy conservation projects reported by political subdivisions



INTEGRATED NO_x EMISSIONS REDUCTION

Integrated Emissions Savings Across Agencies To Report Savings To TCEQ and EPA

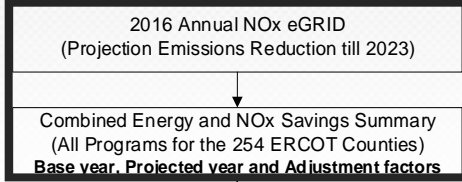


INTEGRATED NO_x EMISSIONS REDUCTION

Integrated Emissions Savings Across Agencies To Report Savings To TCEQ and EPA

State agencies included:

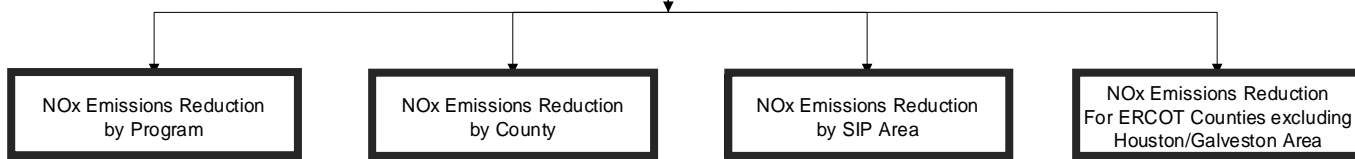
- TEES/ESL
 - PUC
 - SECO
 - ERCOT/Wind
 - SEER 13/14
- Single/Multifamily**



Total savings across agencies

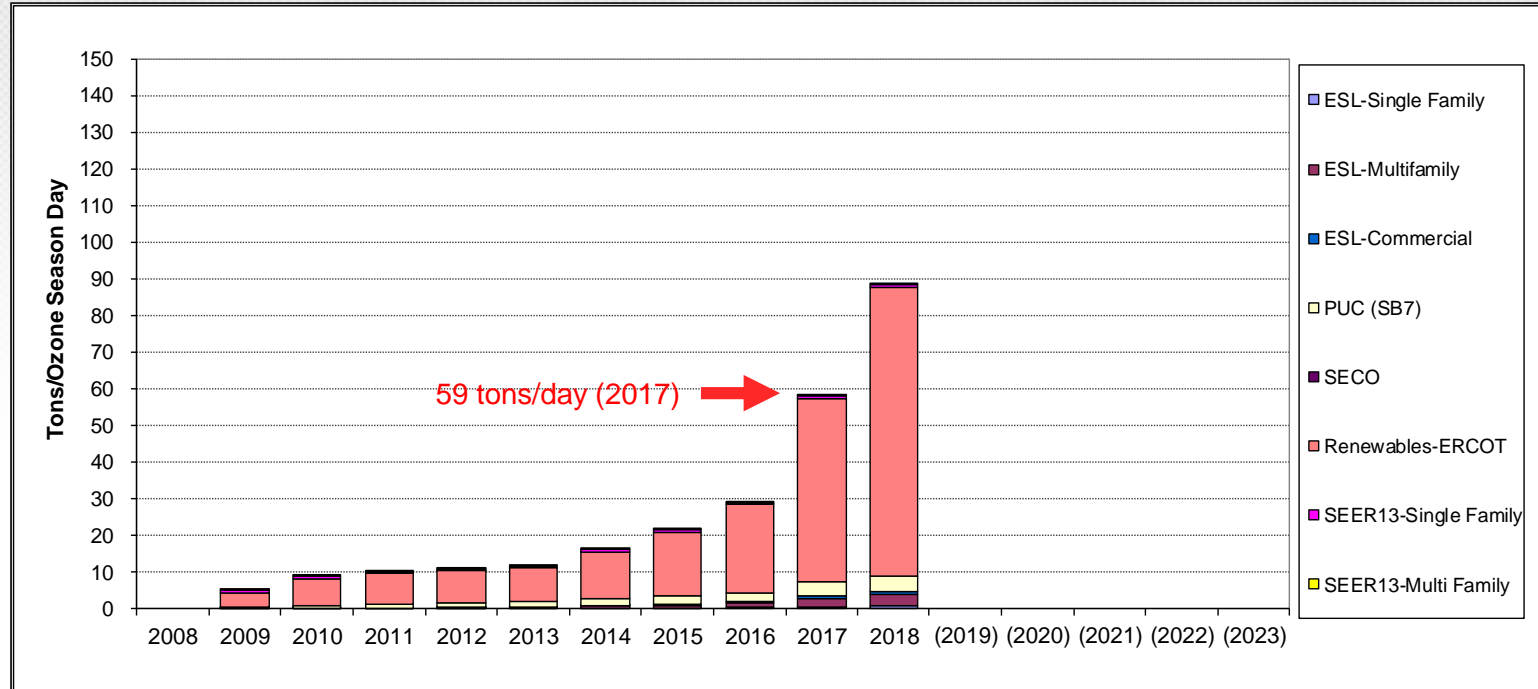
Annual emissions reductions:

- By program
- By county
- By SIP area
- By ERCOT counties



INTEGRATED NO_x EMISSIONS REDUCTION (2008 Baseyear)

2018 Integrated OSP NO_x Emissions Reduction Using new 2016 eGrid

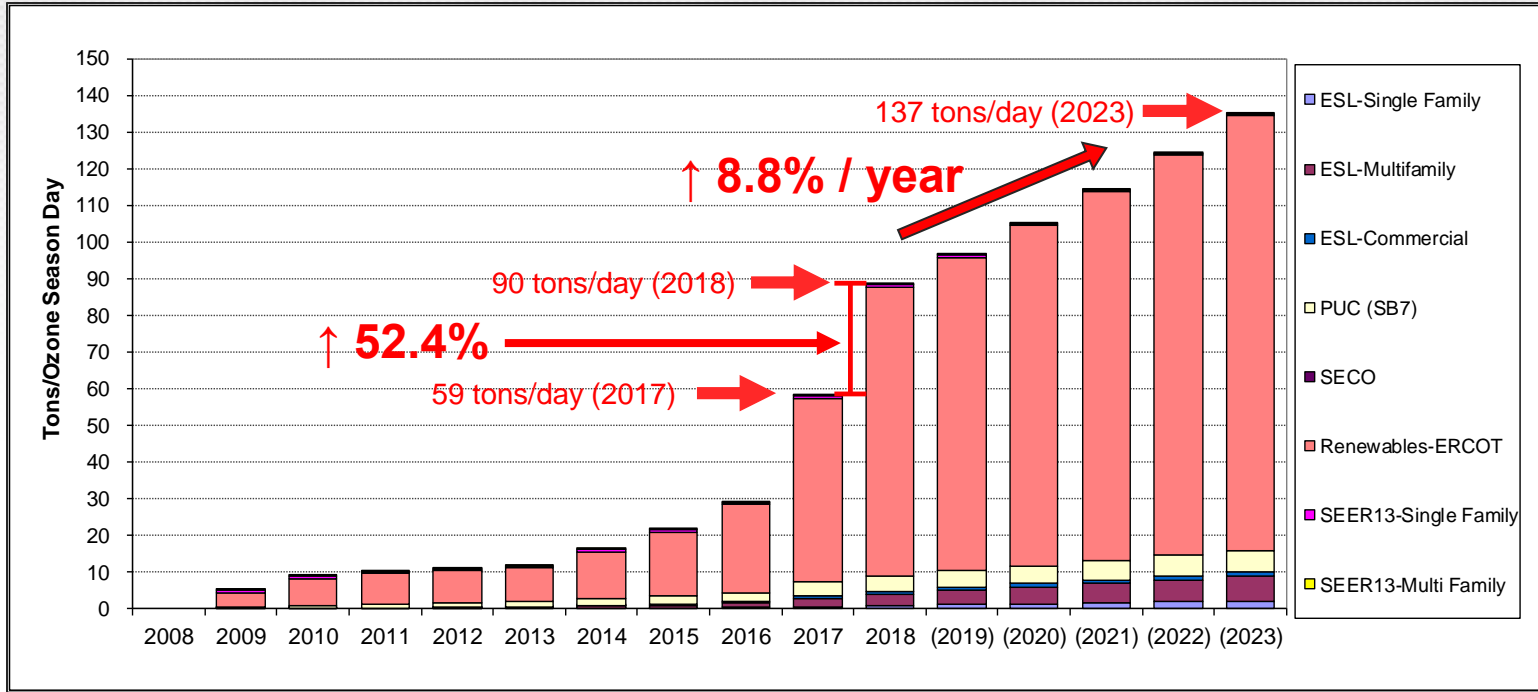


2017 integrated OSP NO_x Emissions Reduction

- ESL Code Compliance (3.51 tons/day)
- PUC SB7 programs (3.75 tons/day)
- SECO Political Sub.* (1.14 tons/day)
- Green Power (Wind) (50.25 tons/day)
- Residential AC Retrofits (0.56 tons/day)
- **Total (2017) (59.21 tons/day)**

INTEGRATED NO_x EMISSIONS REDUCTION (2008 Baseyear)

2018 Integrated OSP NO_x Emissions Reduction Using new 2016 eGrid



2018 integrated OSP NO_x Emissions Reduction

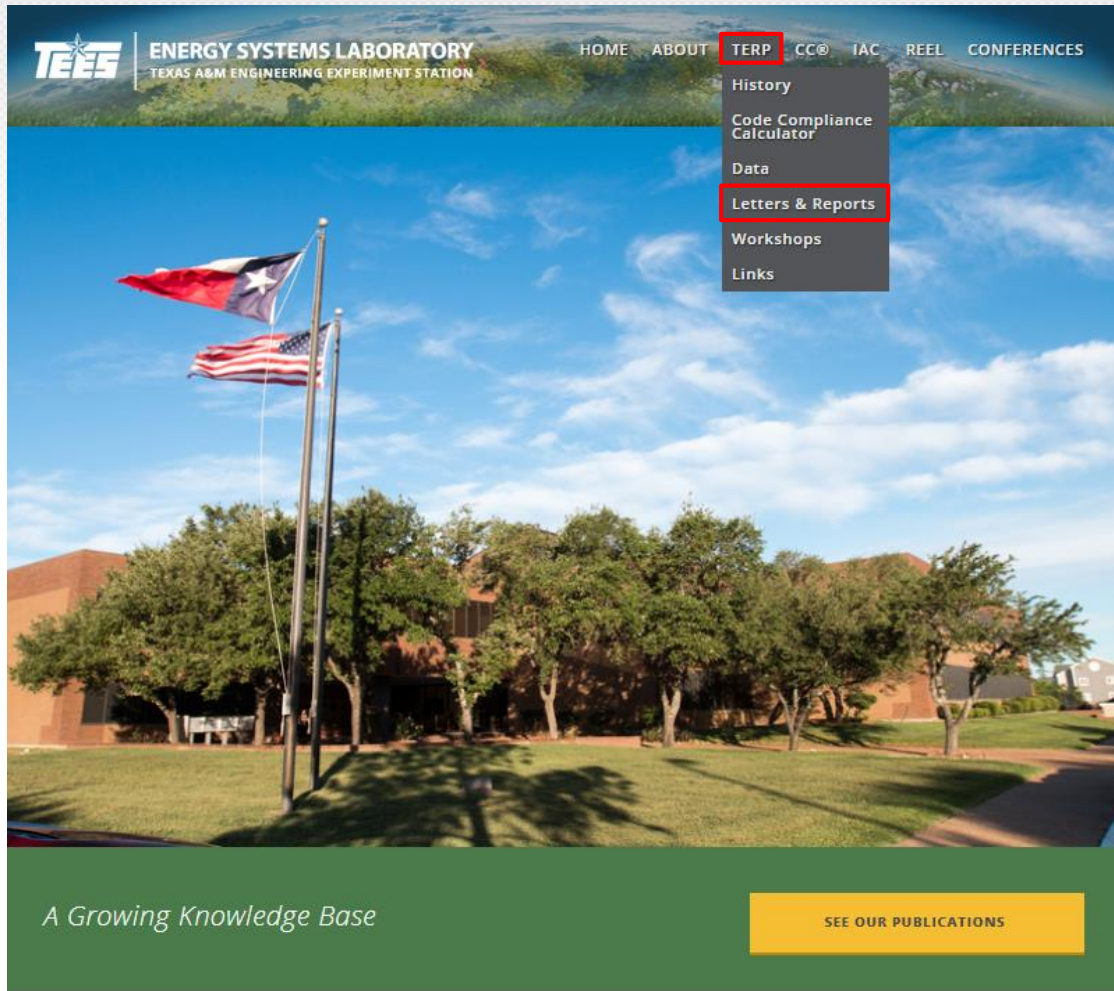
- ESL Code Compliance (4.85 tons/day)
- PUC SB7 programs (4.21 tons/day)
- SECO Political Sub.* (1.30 tons/day)
- Green Power (Wind) (78.80 tons/day)
- Residential AC Retrofits (0.63 tons/day)
- **Total (2018) (89.79 tons/day)**

2023 integrated OSP NO_x emissions reduction

- ESL Code Compliance (10.25 tons/day)
- PUC SB7 programs (5.78 tons/day)
- SECO Political Sub. * (1.75 tons/day)
- Green Power (Wind) (118.49 tons/day)
- Residential AC Retrofits (0.49 tons/day)
- **Total (2023) (136.77 tons/day)**

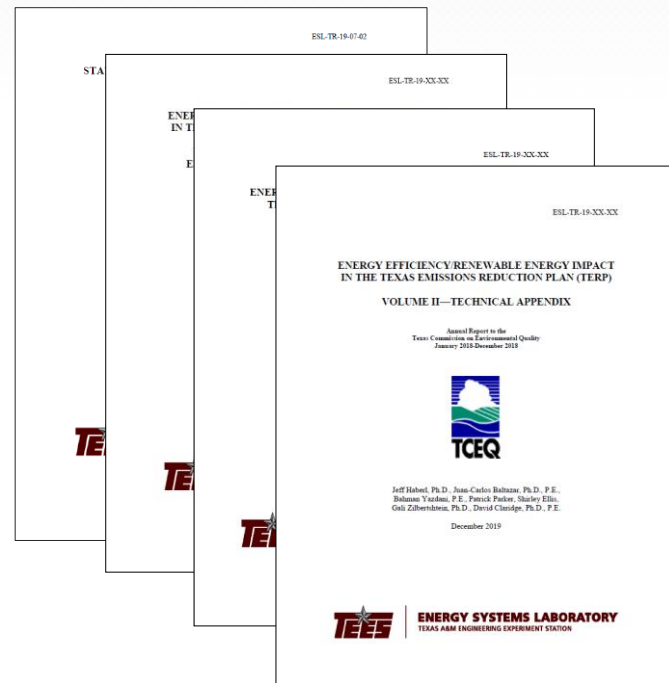
REPORTS AND PAPERS: TERP

Reports: 2002 through 2018



Recent Reports:

- Statewide 2018 Air Emission Calculations from Wind and Other Renewables (Vol I and Vol II)
- TCEQ 2018 Annual Preliminary Report: Integrated NOx Emissions Savings from EE/RE Programs Statewide
- TCEQ 2018 Annual Report Volume I: Technical Report
- TCEQ 2018 Annual Report Volume II: Technical Appendix



REPORTS AND PAPERS: TERP

Publications: 2018

DEVELOPMENT OF A PROCEDURE FOR AUTOMATING THERMAL ZONING FOR BUILDING ENERGY SIMULATION

CH-18-008
Analysis of Whole-Building HVAC System Energy Efficiency

CH-18-006
Commissioning an Existing Heat Recovery Chiller System at a Large District Plant

Comparison of ASHRAE peak cooling load calculation methods

CHUNLEI MAO*, JUAN CARLOS BALTAZAR* and JEFF S. HABERL*
*Department of Building Science, Texas A&M University, Station System, Building 3800B, College Station, TX 77843-3108

Identifying Peak and Base Energy Consumption Hour Ranges for Commercial Buildings Using a Non-Parametric Method

Hongxiang Fu, Juan Carlos Baltazar, PhD, PE
Student Member ASHRAE, Member ASHRAE
David E. Claridge, PhD, PE
Fellow ASHRAE

ABSTRACT
Measured whole building (WB) heating for winter (HW) and electric utility consumption of commercial buildings are of interest to building managers and commissioning engineers for energy optimization. This type of energy consumption typically aligns with winter weather conditions, ventilation, operation, occupancy, and other factors. Even the presence of detection modeling, simplifying the hours into peak or non-occupancy hours is valuable for monitoring building energy consumption and planning energy conservation for multi-building campuses. The proposed method for identifying peak and base energy consumption is suitable for a peak or base occupancy level in each utility according to measured hourly data. It reports the time of day when the building is in the highest or lowest energy hourly consumption state. The method provides time periods during which occupancy rates are consistently higher or lower. The method also indicates when a building has very high peak base and very low base hours (highly variable), and a variety of energy cases when the hourly consumption level of the building does not significantly vary.

INTRODUCTION
Measured energy consumption data from buildings are increasingly requested by building managers and commissioning engineers to identify energy consumption opportunities and detect anomalies. Critical energy consumption (CE) and heating hot water consumption (HHWC) usually have strong dependencies on outdoor weather conditions. Elementary occupancies (EE) tend to have a weak dependence on outdoor weather conditions. The peak base and non-occupancy (NO) are useful for identifying energy conservation opportunities. If base-of-day variables are not seasonally consistent, base-of-day variables may indicate an opportunity (OAT) in the periodic variables have been accepted as the standard method for occupancy modeling.

Shipping Print is published online in the Department of Building Engineering, Texas A&M University, College Station, Texas. Download Online in the Department of Building Engineering, Texas A&M University, College Station, Texas. Download Online in the Department of Building Engineering, Texas A&M University, College Station, Texas.

Literature review of building peak cooling load methods in the U.S.

Energy Strategy Reviews

Building and Environment

Stephen A. Roosa
Steve Doty
Wayne Turner

CHAPTER 27
MEASUREMENT AND VERIFICATION OF ENERGY SAVINGS

JEFF S. HABERL, PH.D., P.E.
CHARLES C. CULP, PH.D., P.E.
Energy Systems Laboratory
Texas A&M University

27.1 INTRODUCTION
Measurement and verification (M&V) has a dual aim. First, M&V quantifies the savings being obtained. This applies to the initial savings and the long-term savings. Since the persistence of savings has been shown to increase with time [1,2], long-term M&V provides data to make these savings sustainable. Second, M&V must be cost effective so that the cost of measurement and the analysis does not consume the available savings [3,4]. The 1997 International Performance Measurement and Verification Protocol (IPMVP) sets the target costs for M&V to be in the range of 1% to 10% of the construction cost for the type of the energy conservation measure. ECM, depending upon the M&V option selected, most approaches fall in the recommended range of 0.5% to 10% of the construction cost. The IPMVP 2001 removed this guidance on the recommended costs for M&V. Currently a goal of about 5% of the savings annually has evolved as a preferred criterion for costing M&V since the cost justification directly results from the calculation. A general procedure for selecting an approach can be summarized by the following five steps:

1. Generally, one wants to attempt to perform monthly utility bill before other analysis.
2. If this does not work, then perform daily or hourly billing before other analysis.
3. If this does not work, then perform component isolation analysis.
4. If this also does not work, then perform a calibrated simulation analysis.
5. This report savings and finish the analysis.

27.2 HISTORY OF M&V
27.2.1 History of Building Energy Measurement
The history of the measurement of building energy use can be traced to the 19th century for electricity and earlier for fuels such as coal and wood, which were used to heat buildings [5-8]. By the 1900s, although electricity was common in many new commercial buildings, its use was primarily for incandescent lighting and, to a lesser extent, for the electric motors associated with ventilating buildings since most of the work in office buildings consisted during daylight hours. The metering of electricity closely paralleled the spread of electric utility cities, with its invention needed to recover the cost of its production through the collection of payments from electric utility customers [9-11]. Commercial meters for the measurement of flowing liquids in pipes can be traced to the same period. The invention of the first commercial flowmeter by Clemens Herschel in 1860 used principles based on the Pitot tube and the Venturi flowmeter, which were invented in 1732 and 1797 respectively by their namesakes [11]. Commercial meters for the measurement of natural gas can likewise be traced to the sale and distribution of natural gas, which paralleled the development of the electric meters.

27.2.2 History of Measurement and Verification in the U.S.
The history of the measurement and verification of building energy use parallels the development and use of computerized energy calculations in the 1960s. Beginning in 1973, this awareness accelerated when the combustion on Midland oil made energy a front page issue [12,13]. During the 1950s and 1960s, most engineering calculations were performed using slide rules, engineering tables, and desktop calculators that could only add, subtract, multiply and divide. Since the public was told to believe energy was cheap and abundant [14], measuring and verifying building energy use was limited mostly to simple, unadorned comparisons of monthly utility bills.

In the 1960s, several others were initiated to formulate and codify equations that could predict dynamic heating and cooling loads, including efforts at the National Bureau of Standards to predict temperatures in hollow slabs [15] and the 1967 F&C program developed by a group of mechanical engineering consultants [16] that used the total equivalent temperature difference (TETD) method. The population

Dissertation 2018:

- Shin, M. "Development of a Procedure for Automating Thermal Zoning for Building Energy Simulation", Ph.D., Department of Architecture, August 2018.

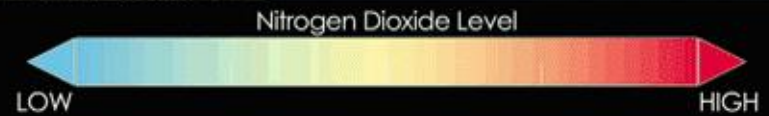
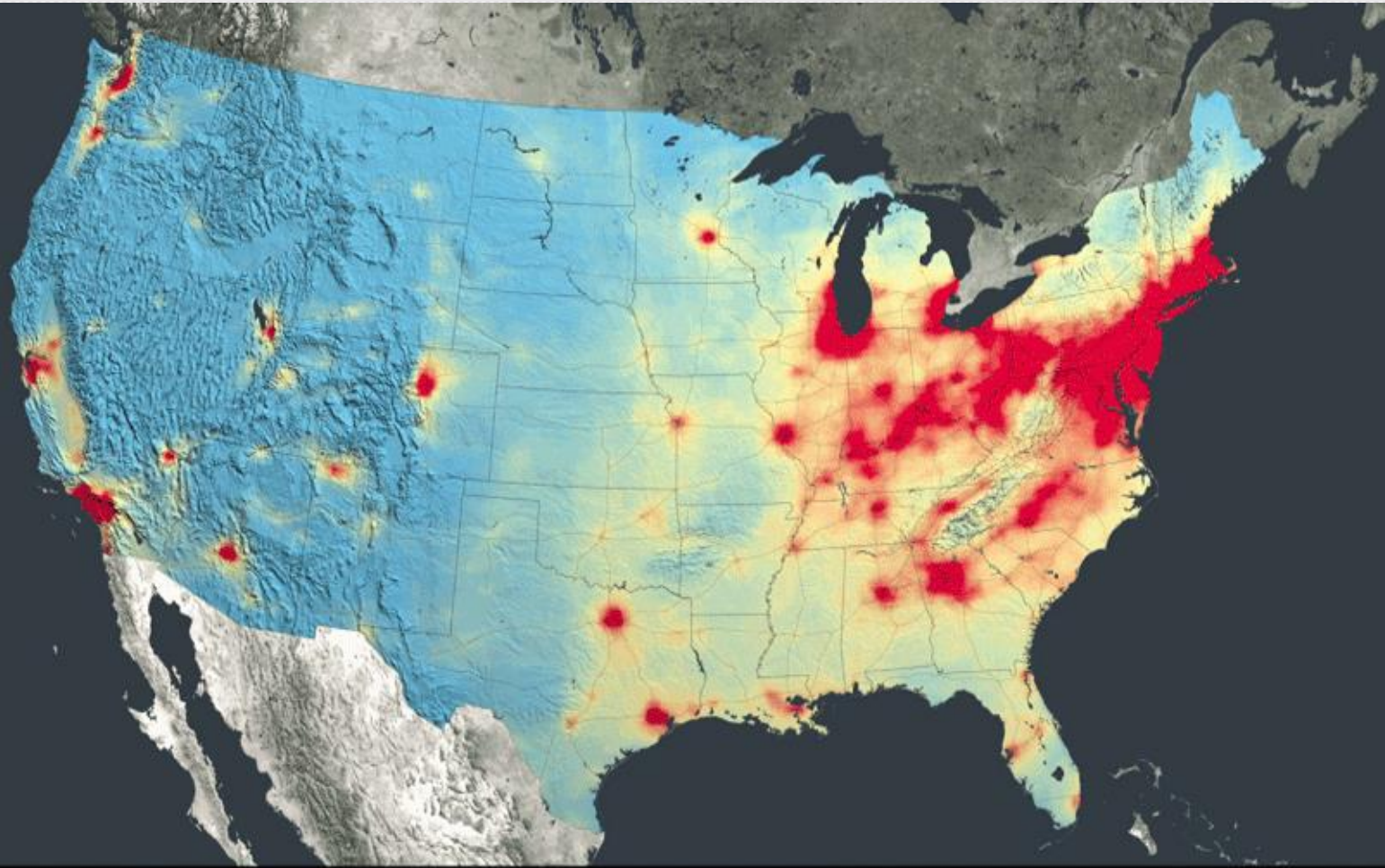
Papers 2018:

- Liao, J., Wang, L., Claridge, D.E., 2018. "Analysis of Whole-Building HVAC System Energy Efficiency", ASHRAE Transaction.
- Wang, L., Sakurai, Y., Bowman, S.J., Claridge, D.E., 2018. "Commissioning an Existing Heat Recovery Chiller System at a Large District Plant", ASHRAE Transaction.
- Mao, C., Baltazar, J., Haberl, J.S., 2018. "Comparison of ASHRAE Peak Cooling Load Calculation Methods", Science and Technology for the Built Environment, Vol 25, pp.189-208.
- Fu, H., Baltazar, J., Claridge, D.E., 2018. "Identifying Peak and Base Energy Consumption Hour Ranges for Commercial Buildings Using a Non-Parametric Method", ASHRAE Winter Meeting.
- Mao, C., Baltazar, J., Haberl, J.S., 2018. "Literature Review of Building Peak Cooling Load Methods in the United States", Science and Technology for the Built Environment, Vol 24, pp.228-237.
- Weijermars, R., Burnett, D., Claridge, D.E., Noynaert, S., Pate, M., Westphal, D., Yu, W., Zuo, L., 2018. "Redeveloping Depleted Hydrocarbon Wells in an Enhanced Geothermal System (EGS) for a University Campus: Progress Report of a Real-Asset-Based Feasibility Study", Energy Strategy Reviews.
- Chen, W.j., Claridge, D.E., Liao, J., 2018. "Using a Chain Recoling System on Buildings in Hot and Humid Climates", Building and Environment.

Chapters Written and Volumes Edited 2018:

- Haberl, J.S., Culp, C., 2018, "Measurement and Verification of Energy Savings", Chapter 27 in Roosa, S., Doty, S. and Turner, W.C., eds., Energy Management Handbook, 9th edition, Fairmont Press.

U.S. AIR QUALITY IMPROVEMENT FROM 2005 - 2018



Source from NASA: http://www.nasa.gov/content/goddard/new-nasa-images-highlight-us-air-quality-improvement/#.U_-CNxzKbxQ

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<http://esl.tamu.edu/terp>

