



A generalized method for estimation of industrial energy savings from capital and behavioral programs

Industrial Energy Technology Conference

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May 20, 2011

Agenda



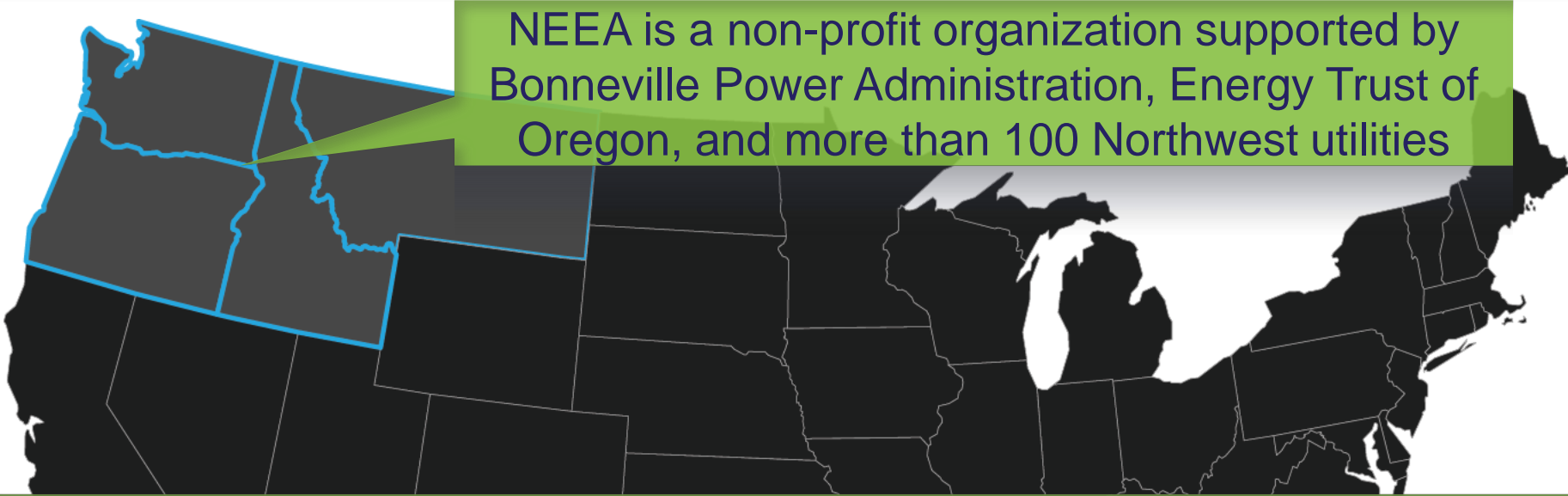
Background

Model Specification

Model Application

Questions

Northwest Energy Efficiency Alliance (NEEA)



NEEA is a non-profit organization supported by Bonneville Power Administration, Energy Trust of Oregon, and more than 100 Northwest utilities

Our ***purpose*** is to maximize energy efficiency.

Three ***pillars*** to our work:

1. Accelerating market adoption
2. Regional advantage
3. Filling the pipeline

NEEA's Industrial Hypothesis

Strategic Energy Management (SEM)* leads to persistent measureable energy savings.

Testing the hypothesis:

- Develop SEM program called Continuous Energy Improvement (CEI)
- Deploy CEI at selected NW industrial facilities
- Measure energy savings
- Validate results



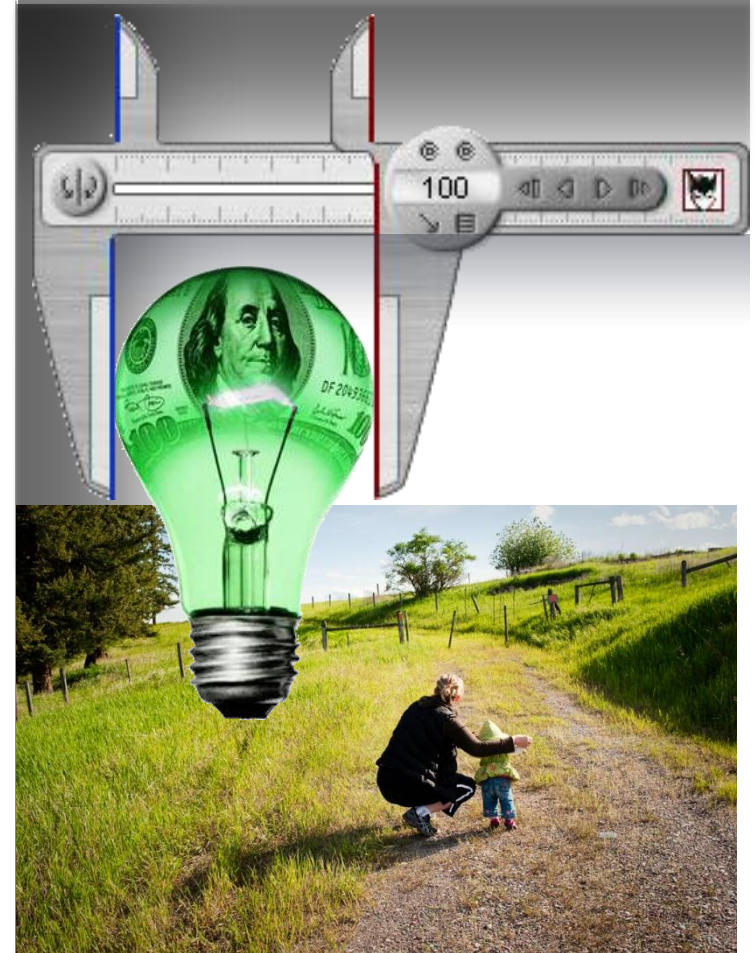
Measuring Behavioral Energy Savings

Savings from behavioral or business practice change programs occur from:

- increased awareness
- modified work procedures
- executive sponsorship
- goal setting
- management review
- active energy team
- acceleration of projects

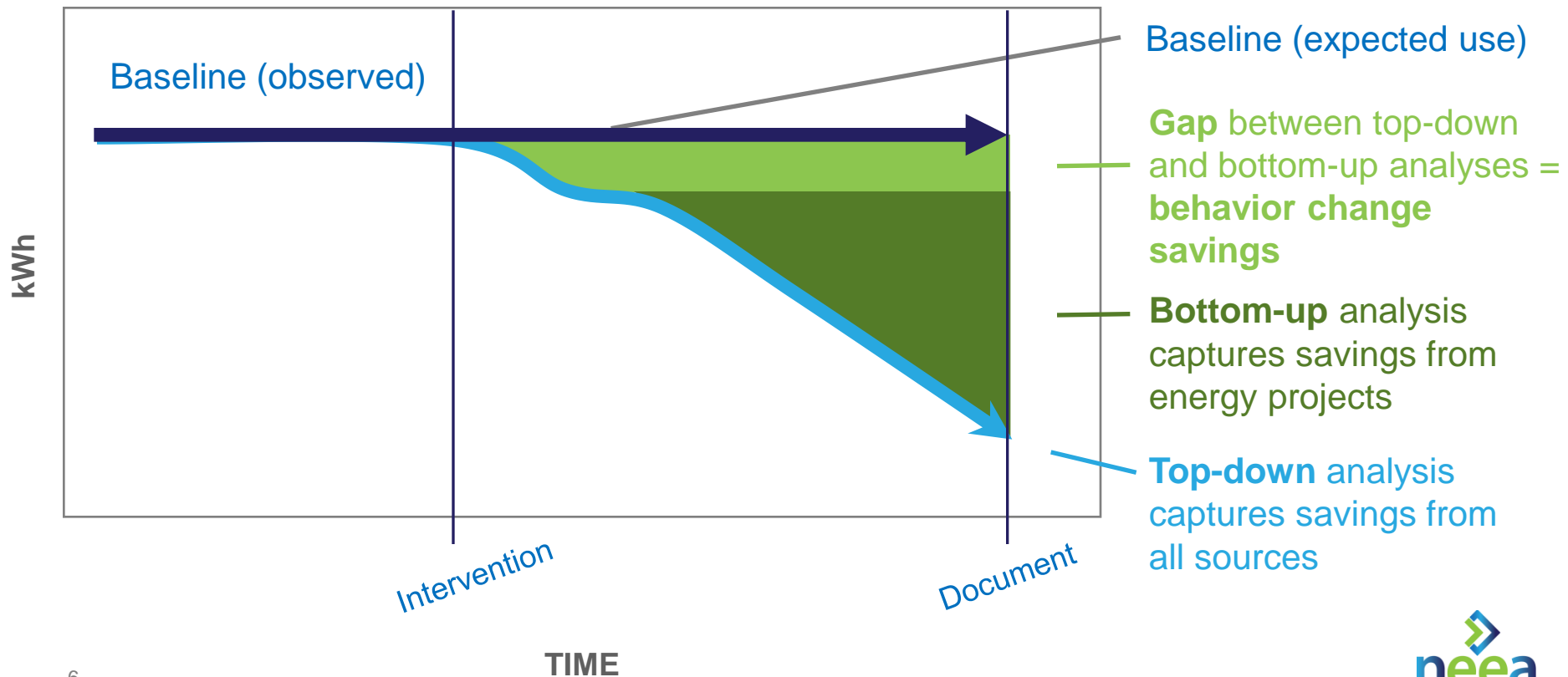
Challenge:

Measure (in kWh) an impact that you can not see or observe?



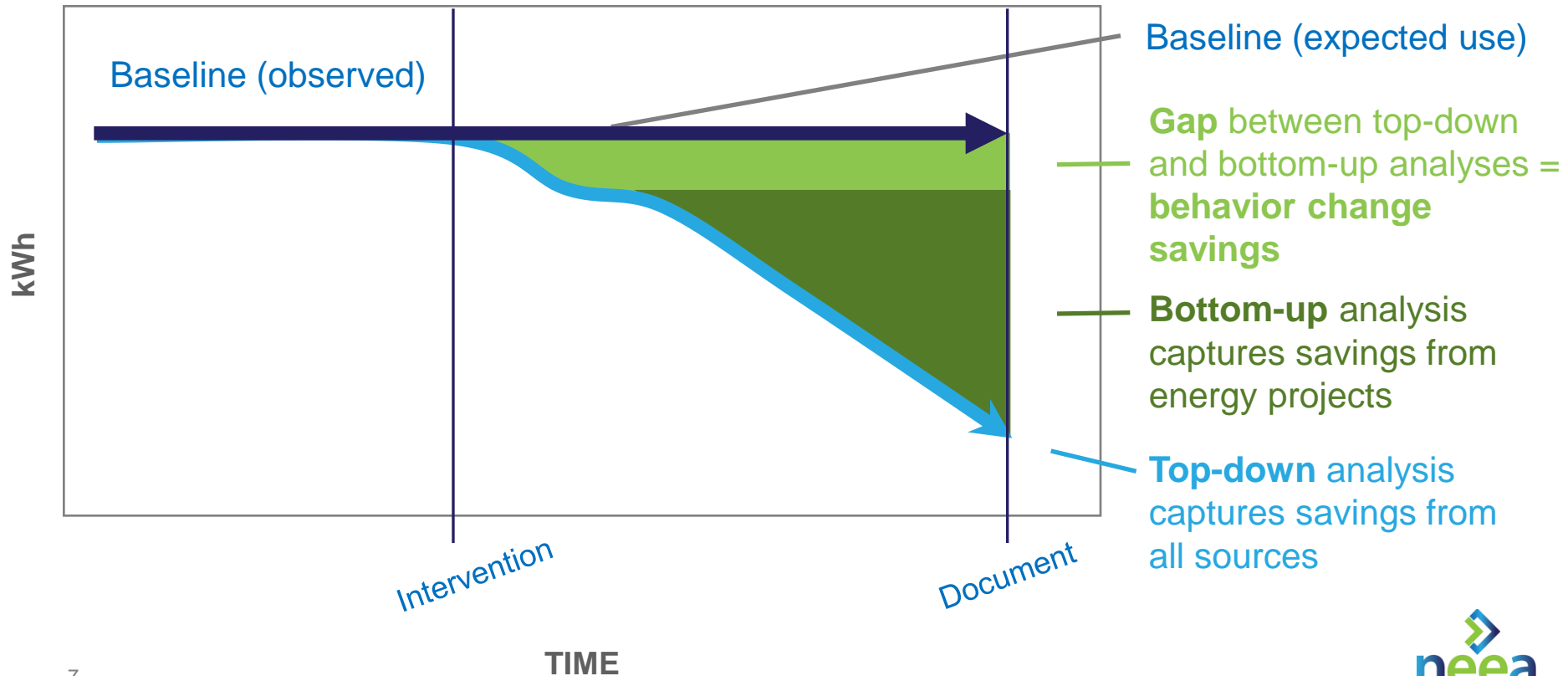
Measuring Behavioral Energy Savings

- Measure energy savings from all sources.
 - Model total energy consumption using generalized linear regression to account for primary energy drivers
 - Estimate energy savings using an intervention parameter



Measuring Behavioral Energy Savings

- Measure energy savings from all sources.
- Subtract energy savings from projects.
- The balance is energy savings from behavior change.

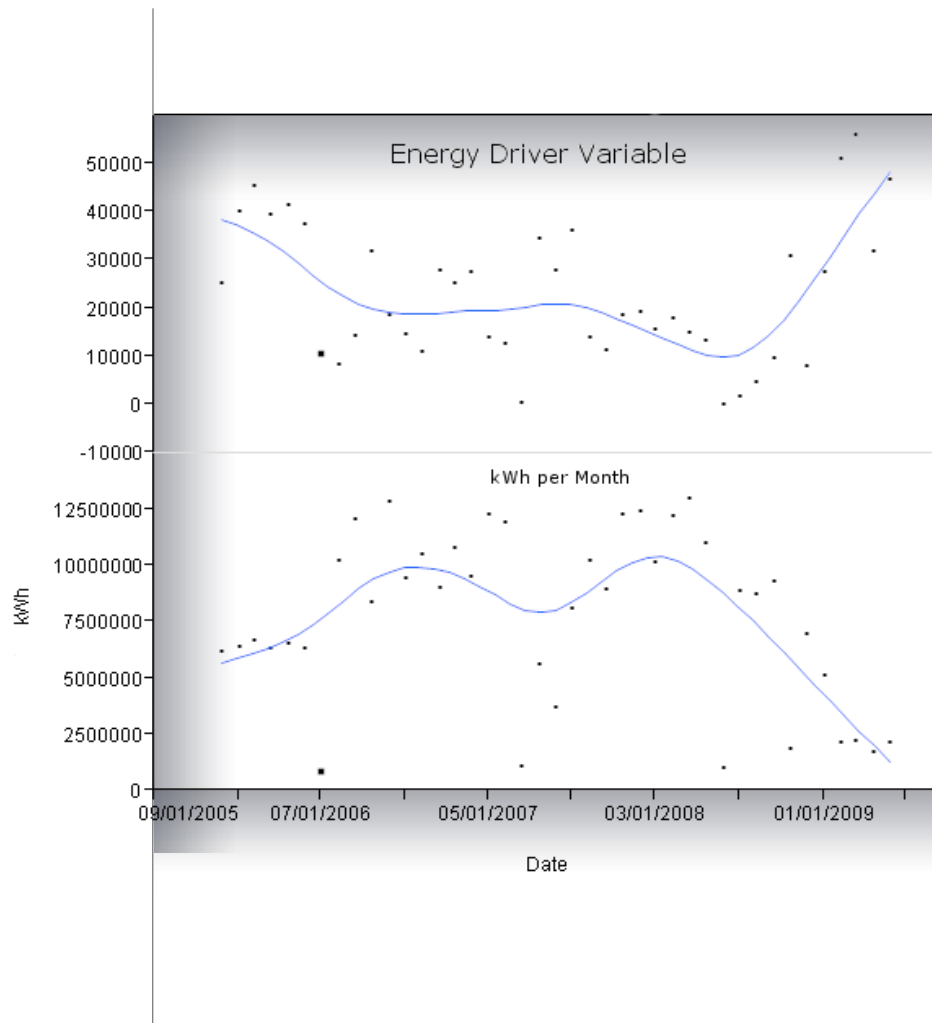


Modeling Industrial Energy Consumption

An **energy driver** is any variable whose change in value results in a change in energy consumption. They are widely varied and often industry dependent.

Common energy drivers are:

- Production output
- Weather
- Raw material quality
- Maintenance events
- Process yield
- ... the phase of the moon

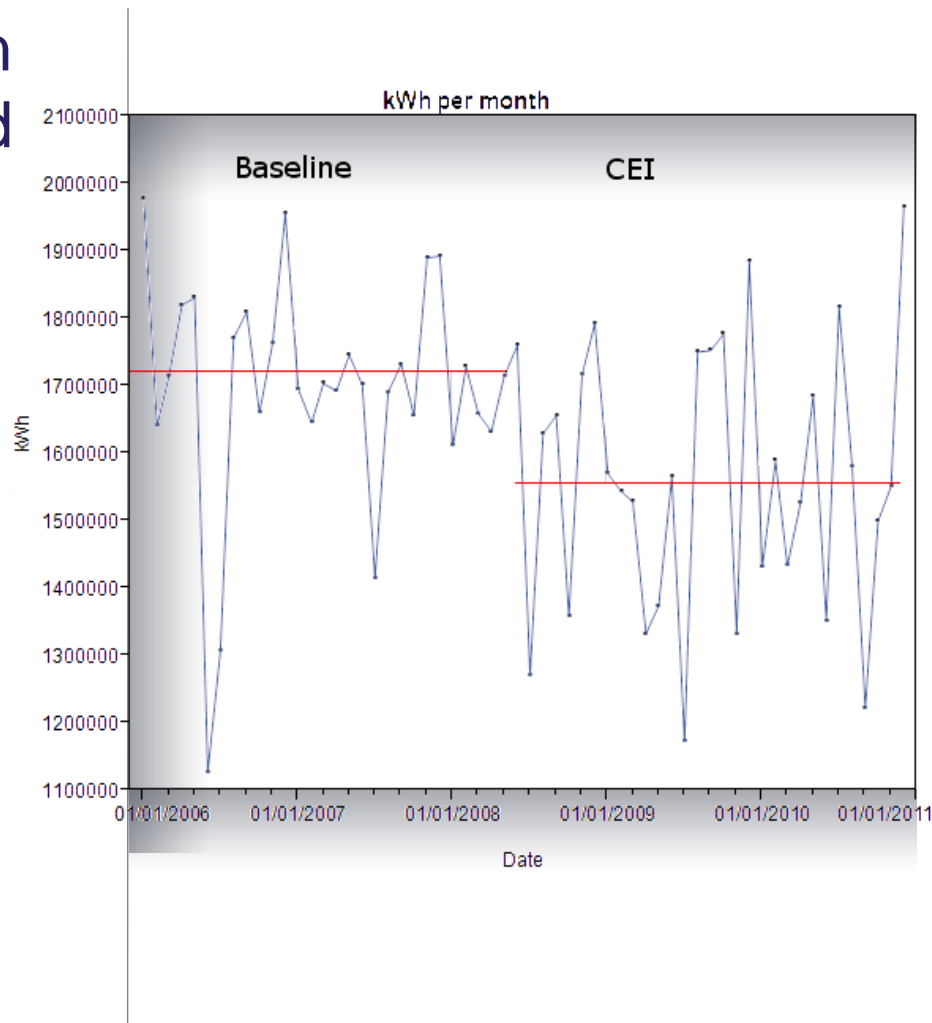


Modeling Industrial Energy Consumption

Industrial energy consumption patterns are widely varied and typically industry dependent.

The impact of an energy program can be observed as:

- Step Change

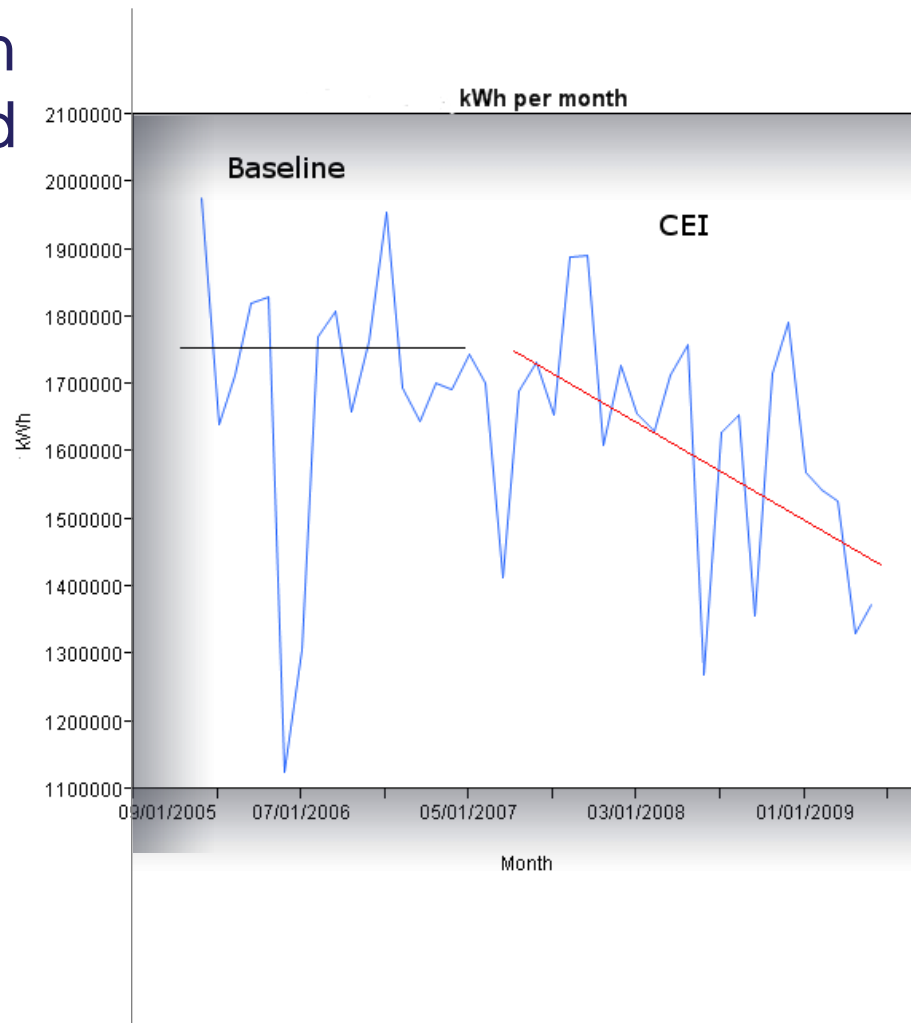


Modeling Industrial Energy Consumption

Industrial energy consumption patterns are widely varied and typically industry dependent.

The impact of an energy program can be observed as:

- Step Change
- Change in trend

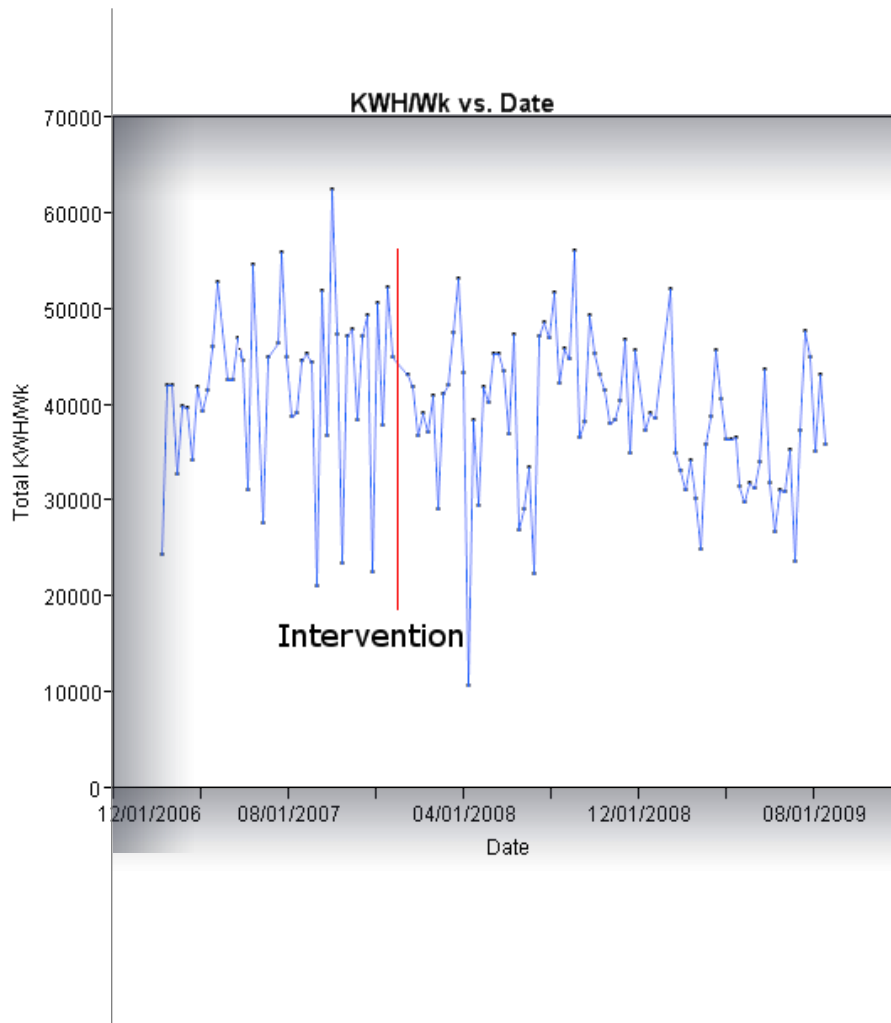


Modeling Industrial Energy Consumption

Industrial energy consumption patterns are widely varied and typically industry dependent.

The impact of an energy program can be observed as:

- Step Change
- Change in trend
- No apparent change



Warning: Scary Slides Ahead

MODEL SPECIFICATION

Generalized Energy Consumption Model

- Intervention Step form

$$kWh_i = \beta_0 + \beta_1 Intervention_i + \sum \beta_j EnergyDriver_{ji} + \varepsilon_i$$

Where : kWh _i	= Total Electricity use per period i
Intervention	= Indicator variable 0 = Before Intervention 1 = After Intervention
EnergyDriver _j	= Any variable that significantly impacts energy consumption
β_1	= Estimated impact of intervention per time period
β_j	= Coefficient for EnergyDriver _j
ε	= Normally distributed error
i	= Time period index
j	= Index for the j th EnergyDriver

Generalized Energy Consumption Model

- Intervention Trend form

$$kWh_i = \beta_0 + \beta_1 TrendBaseline_i + \beta_2 TrendIntervention_i + \sum \beta_j EnergyDriver_{ji} + \varepsilon_i$$

Where : kWh _i	= Total Electricity use per period i
Trend(B)(I)	= Scaled trend variable
β_1 β_2	= Estimated change in energy consumption per time period
EnergyDriver _j	= Any variable that significantly impacts energy consumption
β_j	= Coefficient for EnergyDriver _j
ε	= Normally distributed error
i	= Time period index
j	= Index for the j th EnergyDriver

Calculating Energy Savings

- Intervention Step form
 - If β_1 is significantly different from zero AND negative then
 $TotalSavings = n * \beta_1$ where $n = \#$ of periods post intervention
- Intervention Trend form
 - Perform trend hypothesis test

H_0 : Trend Baseline = Trend Intervention (Intervention had no effect on energy consumption)

H_1 : Trend Baseline \neq Trend Intervention (Intervention had an effect on energy consumption)

$$t = \frac{\beta_{Baseline} - \beta_{Intervention}}{\sqrt{Var(\beta_{Baseline}) + Var(\beta_{Intervention})}}$$

- If Trend Intervention is statistically significant different from AND less than Trend Baseline then

$$TotalSavings = \sum_{i=1}^n i * (\beta_{Baseline} - \beta_{Intervention})$$

where $n = \#$ of periods post intervention

APPLICATION EXAMPLE

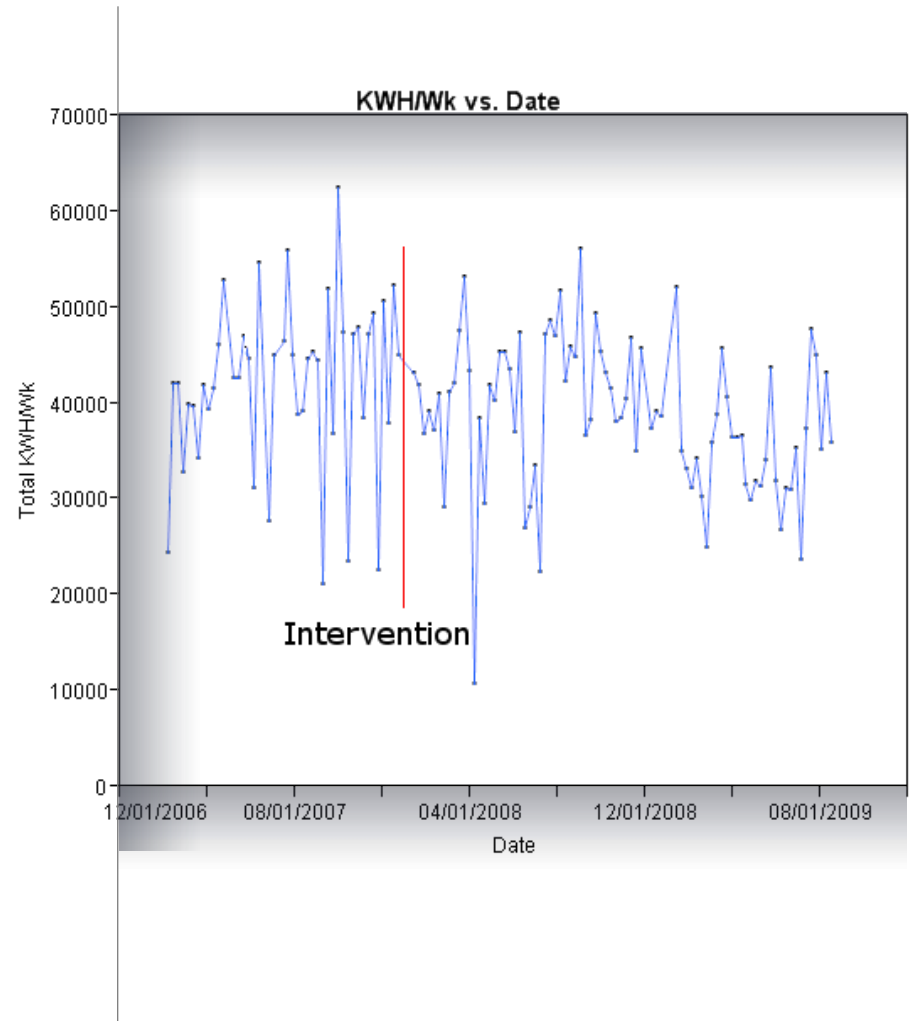
Application Guidelines

The **Intervention Step** form of the model should be used except where:

- The data clearly indicates the intervention resulted in a linear change in energy consumption trend or
- There is significant interest in both the total impact of the intervention AND the rate of consumption change or
- Energy consumption has increased from baseline, but at a rate less than what would have occurred without the intervention

Modeling Application

- No apparent change, but facility was convinced CEI was saving energy
- Model using total production and weather resulted in a poor fit



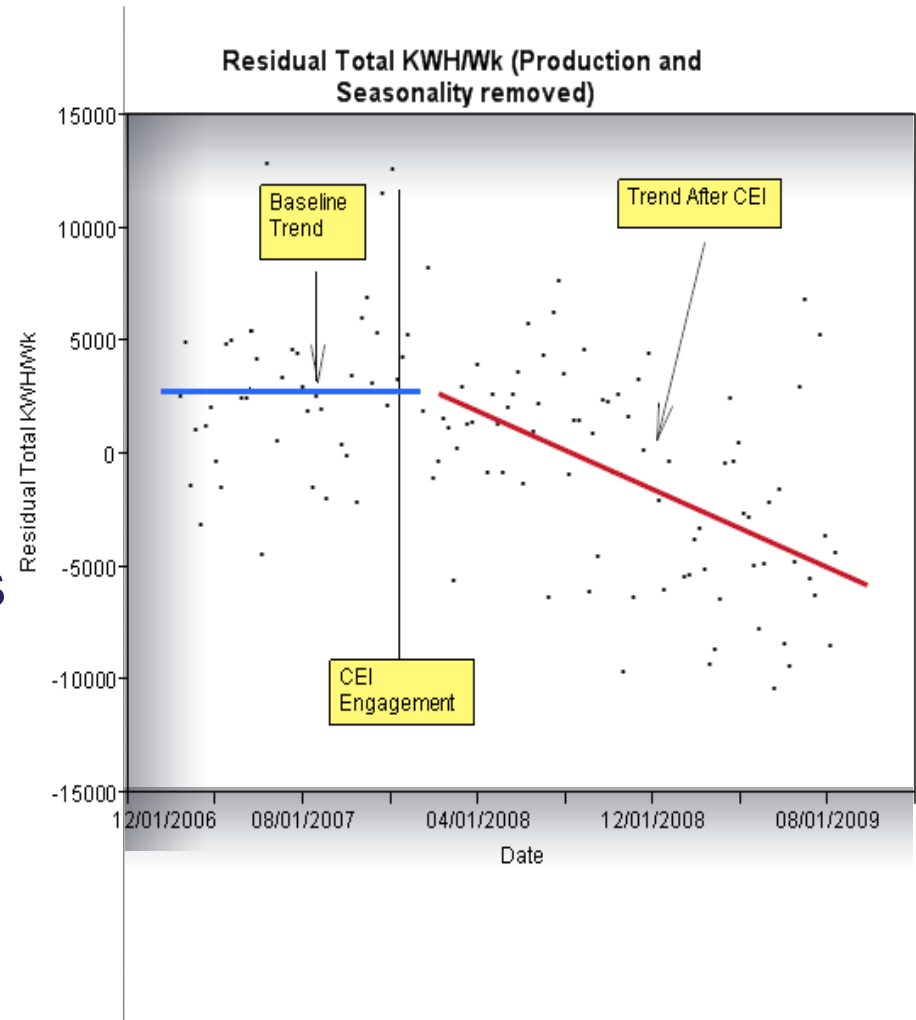
Modeling Application

- No apparent change, but facility was convinced CEI was saving energy
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- Investigation revealed facility produced 3 products each of which required a different amount of energy.



Modeling Application

- No apparent change, but facility was convinced CEI was saving energy
- Model using total production and weather resulted in a poor fit
- Investigation revealed facility produced 3 products each of which required a different amount of energy.
- Refit model with production volume per period for each product. Residuals showed distinct trend.



Model Diagnostics

$$kWh_i = \beta_0 + \beta_1 TrendBaseline_i + \beta_2 TrendCEI_i + \beta_3 Temp_i + \sum \beta_j Product_{ji} + \varepsilon_i$$

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	6	6306098837	1.051e+9	58.2140
Error	117	2112361677	18054373	Prob > F
C. Total	123	8418460515		<.0001*

Summary of Fit

RSquare	0.74908
RSquare Adj	0.736212
Root Mean Square Error	4249.044
Mean of Response	39965.45
Observations (or Sum Wgts)	124

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	9389.5455	2649.827	3.54	0.0006*
Temp	282.64545	37.5897	7.52	<.0001*
Trend Baseline	39.535006	34.82398	1.14	0.2586
Trend CEI	-74.80843	16.91069	-4.42	<.0001*
Formulated	0.0135482	0.004114	3.29	0.0013*
Conc.	0.0273847	0.002103	13.02	<.0001*
Flakes	0.0446901	0.003251	13.75	<.0001*

TrendCEI statistically different from 0 and negative.

Have we proven energy savings?

- Good overall fit with strong ANOVA F statistic and acceptable R²
- Residual analysis showed no unusual characteristics

Model Diagnostics

H_0 : Trend Baseline = Trend CEI (CEI had no effect on energy consumption)

H_1 : Trend Baseline \neq TrendCEI (CEI did have an effect on energy consumption)

$$t = \frac{\text{TrendBaseline} - \text{TrendCEI}}{\sqrt{\text{Var}(\text{TrendBaseline}) + \text{Var}(\text{TrendCEI})}} = \frac{39.5 - (-74.8)}{\sqrt{34.8^2 + 16.9^2}} = -2.95 \quad \text{Prob}>|t| < .001$$

- Energy savings have been demonstrated because TrendCEI is statistically significantly less than TrendBaseline

Estimated Savings (kWh) through 86 weeks of intervention
$\sum_{i=1}^{86} i * (39.5 - (-74.8)) = 427,596 \text{ kWh}$
90% Confidence Interval (189,521 < kWh Savings < 665,671)

CEI Validated Program Results (2006–2010)*

The long story

- 15 CEI implementations from 2006-9
- Cadmus validated data, models, and physical site validation of capital projects.
- Validated top down analysis resulted in significantly more savings than could be accounted for by capital projects.
- The “Net top down” are savings associated the business practice/behavior change and are **50%** of the total savings
- Savings by source proportional to consumption by source

The short story

Implementation of Strategic Energy Management Systems result in ~ 3% per year reduction in energy costs for all sources of energy.

Validated Electric Savings

O&M + Capital (aMW)	Net Top-Down (aMW)	Total Electric Savings (aMW)
8.053	2.961	11.013

1 aMw = 8760 MWh = 8,760,000 kWh

Validated Natural Gas Savings

O&M (therms)	Net Top-Down (therms)	Total Gas Savings (therms)
2,289,164	4,710,318	6,999,482

1 therm = 100,000 BTU = 29.3 kWh

Total savings equivalent to powering more than 15,000 homes for a year

3% of electric and natural gas consumption per year

Key points to remember

- Flexible methodology – handles a broad ranges of energy consumption modeling scenarios
 - Maximizes use of available data – minimizes impact of forecasting error associated with separate baseline/treatment models
 - Provides very robust estimates of energy savings
 - Easy to implement – General linear regression - no magic
- Every modeling scenario is different – be wary of “one size fits all approaches”
 - Search for hidden energy drivers – use on site interviews and residual analysis
 - The better your model fit the better your ability to detect whether any energy was saved.

Questions?



More information about NEEA and NEEA's Industrial Initiative can be found at neea.org

The validation of the modeling methodology and energy savings resulting from the Industrial Initiative can be found in “NEEA Market Progress Evaluation Report #6: Evaluation of NEEA's Industrial Initiative (E11-220)” prepared by the Cadmus Group, Inc. and released on 2/08/11. The document can be found at:

<http://neea.org/research/reports/E11-220A.pdf>