Dynamic Energy and Environmental Dispatch: Achieving co-benefits of power systems reliability and air quality

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Acknowledgement: Collaborations with Mike Swider and Wesley Hall at NYISO; Valuable discussions with Tim Mount, Bill Schulze, Bob Thomas, Dan Shawhan and Ray Zimmerman.

High Electric Demand Days (HEDD): A “peak” problem

- Heat Waves
- Power Systems
  - **Reliability** is compromised
  - **Cost** of electricity is high: expensive peaking generators
- Environment
  - High **ozone** air pollution
  - ***Double threats*** to public health: *heat* and *air pollution*

New York City

Station	County	NYS ID	4th Max	13 May	28 May	10 Jun	20 Jun	21 Jun	28 Jun	29 Jun	30 Jun	1 Jul	13 Jul	17 Jul	18 Jul
Babylon	Suffolk	5150-02	**0.083**		0.079		0.095	0.086			0.078	0.083			0.082
Holtsville	Suffolk	5151-10	**0.079**				0.092	0.080				0.076			0.079
Riverhead	Suffolk	5155-01	**0.083**				0.084	0.083				0.078			0.088
CCNY	New York	7093-25	0.073											0.077	
Pfizer Lab	Bronx	7094-10	0.075		0.076	0.077								0.080	
Queens College 2	Queens	7096-15	**0.082**				0.077	0.080	0.080	0.083		0.082		0.082	0.086
Susan Wagner	Richmond	7097-01	**0.077**	0.077			0.076	0.082	0.078	0.084					
White Plains	Westchester	5902-04	0.072										0.080	0.086	
Temperature				**81**	**89**	**84**	**94**	**94**	**88**	**93**	**93**	**94**	**89**	**96**	**100**

Washington DC Metropolitan Area

S	M	T	W	T	F	S
June 2012			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

S	M	T	W	T	F	S
July 2012					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

Air Quality Index (AQI) Category
Very Unhealthy
Unhealthy
Unhealthy for sensitive groups
Moderate
Good

Get Creative!

USA TODAY (July 4, 2012):
"In New York City, police officers drive through streets using loudspeakers asking people to turn down their air conditioning during the day. The power grid can't handle it."

MOU among Northeastern States to reduce HEDD emissions

State	NOx (tons per day)	Percent Reduction from HEDD Units
CT	11.7	25%
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- "**Conflict**" between power systems reliability and air quality
  - Currently the mechanisms for achieving the reductions proposed by air quality regulators emphasize on emission controls of peaking units.
  - Con Edison's review indicated that peaking units play important roles in reliability, black start, load pocket support, and voltage support.
  - A 2009 NYISO analysis showed that proposed HEDD programs may lead to "exceedances of reliability criteria".

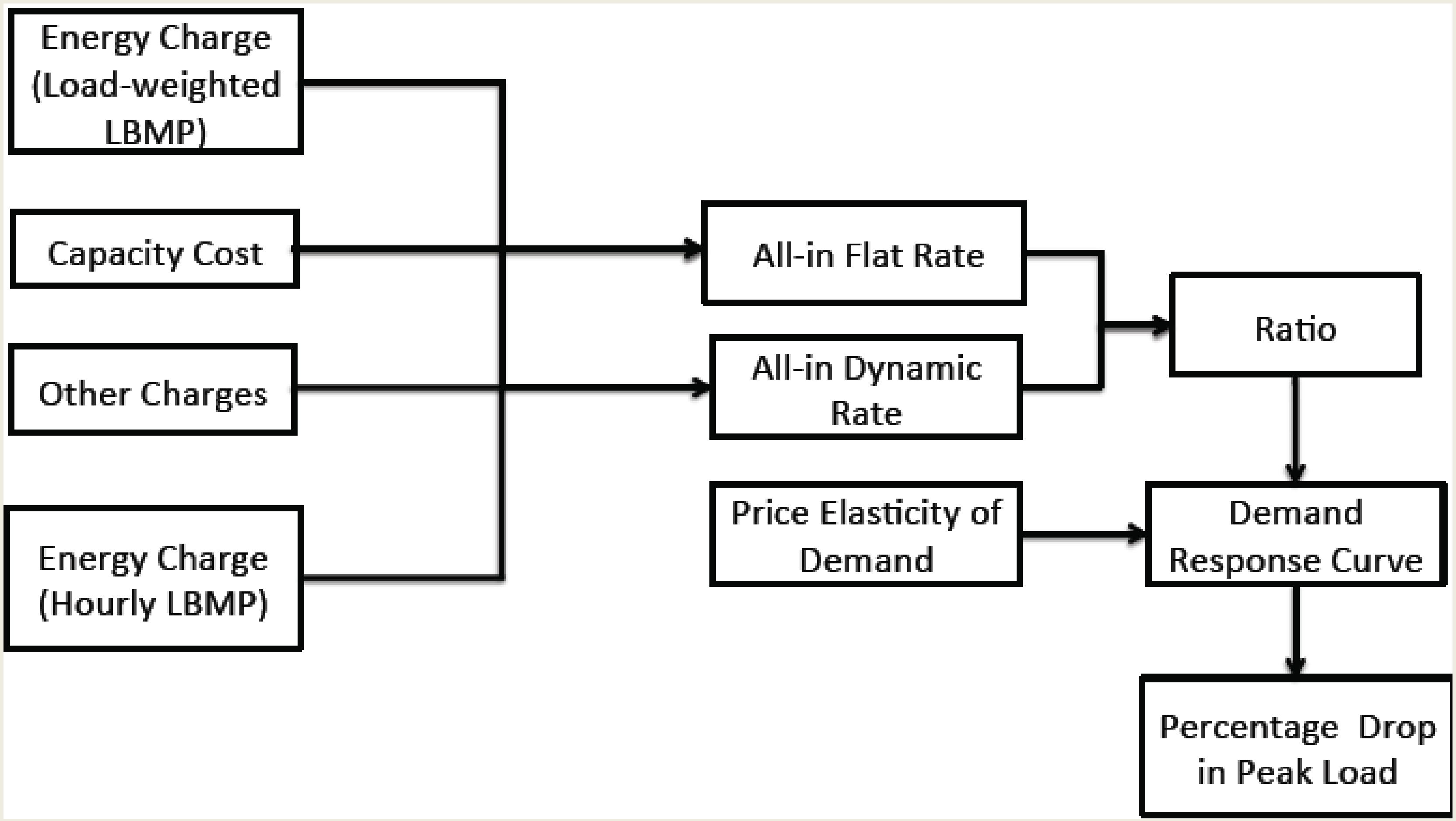
Our Vision for HEDD

- **Supply side**: incorporating air quality forecasting into wholesale day-ahead and real-time electricity markets;
  - dispatching generators taking into account the time- and location-dependent contributions of their **NOx emissions** to ozone formation
- **Demand side**:
  - **Dynamic prices** of electricity linked to wholesale LBMP to incentivize load reduction from critical peak hours
  - Deployment and smart management of **building thermal storage** to shift loads from critical peak hours
  - incentivize the off- peak charging of **electric vehicles** as those vehicles penetrate into the automotive market, shifting daytime mobile emissions to nighttime point source emissions
- **Hypothesis**: the overall costs to the society in achieving those benefits will be lower than acting on the power reliability and air quality separately.

Major Achievements in Year One

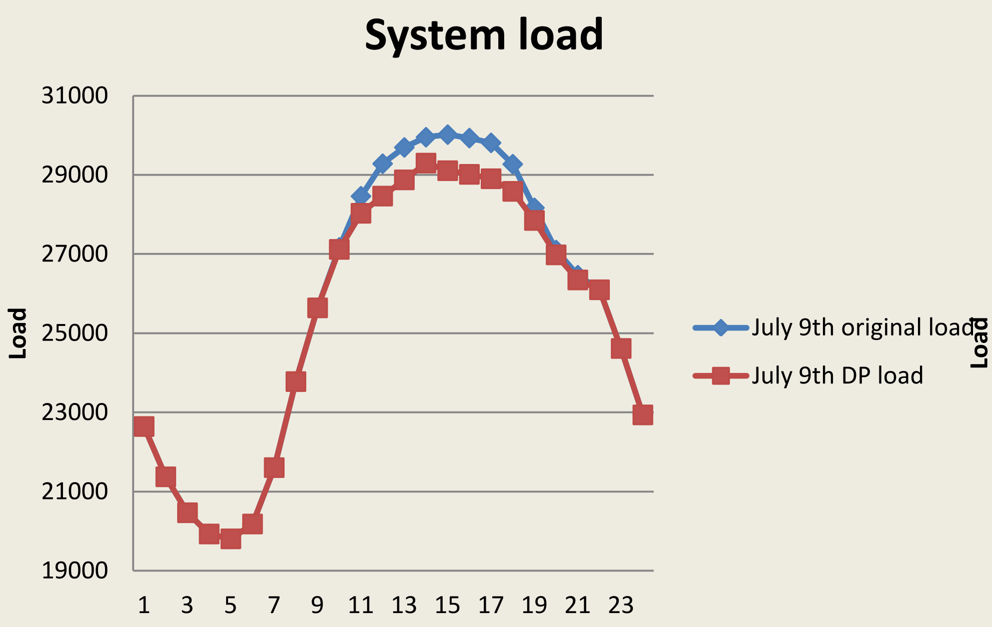
- Emission modeling (in collaboration with NYISO)
- Dynamic pricing modeling (in collaboration with NYISO)
- Thermal storage modeling
- Assessment of emission impacts from
  - Dynamic pricing
  - Thermal storage
  - Challenges

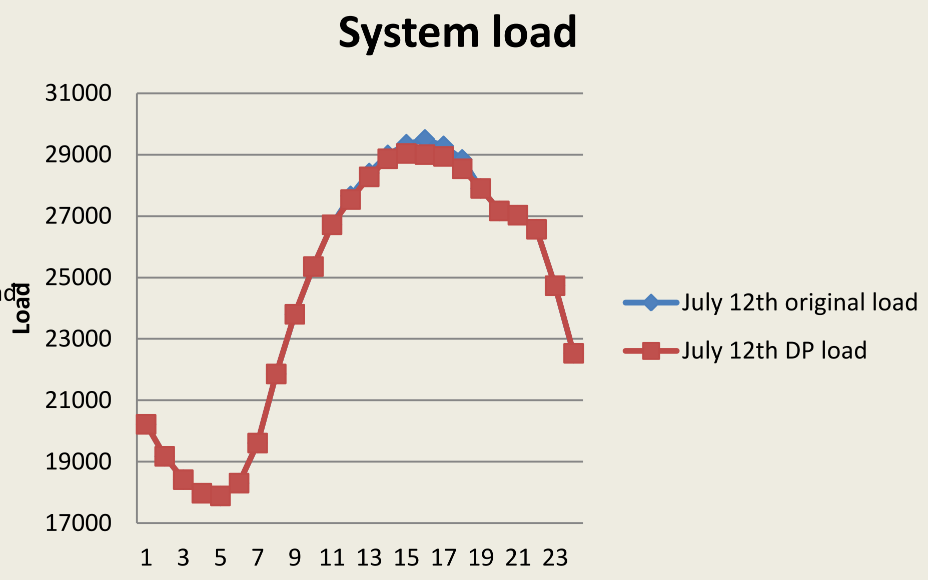
Dynamic Pricing (with NYISO)

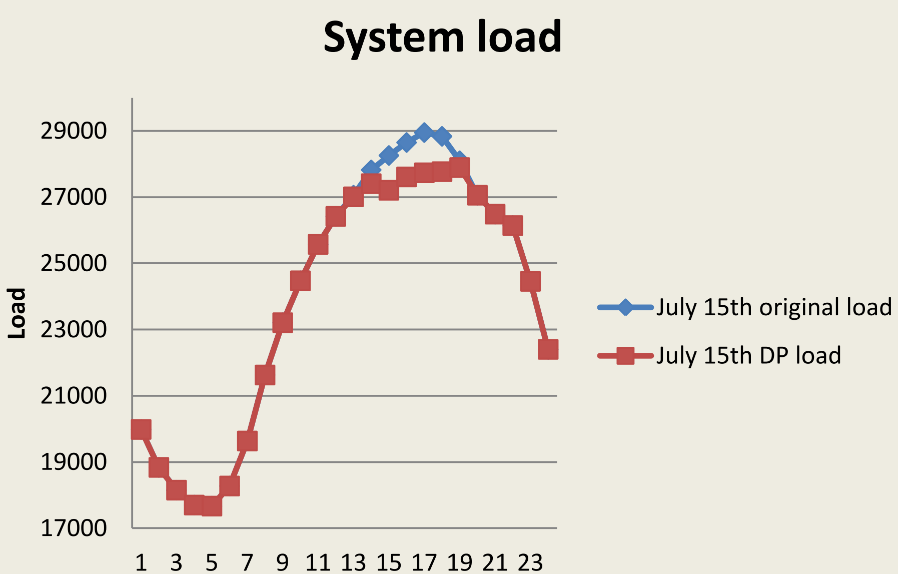


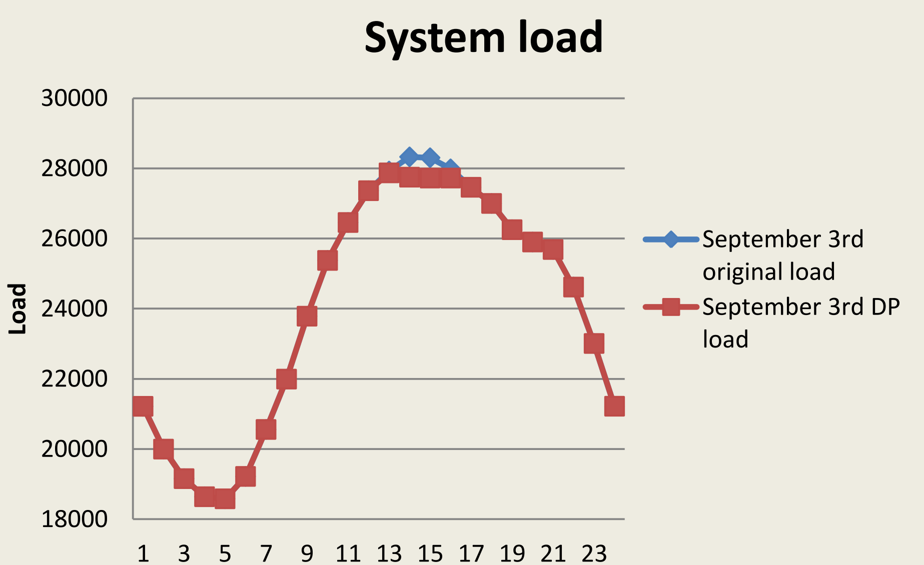
Load Responses

- Critical hours
  - Spread over 90/50/80 highest load hours for NYC, Long Island and the rest of the New York State, depending on market conditions and customer responsiveness
  - Capacity costs applied only during critical peak hours
- Elasticity
  - For residential: from multi-year pilot in Northern Illinois. More recent data can be incorporated.
  - For Commercial and Industrial: non-experimental programs in the eastern US.
  - Applied for Critical Peak period price ratio

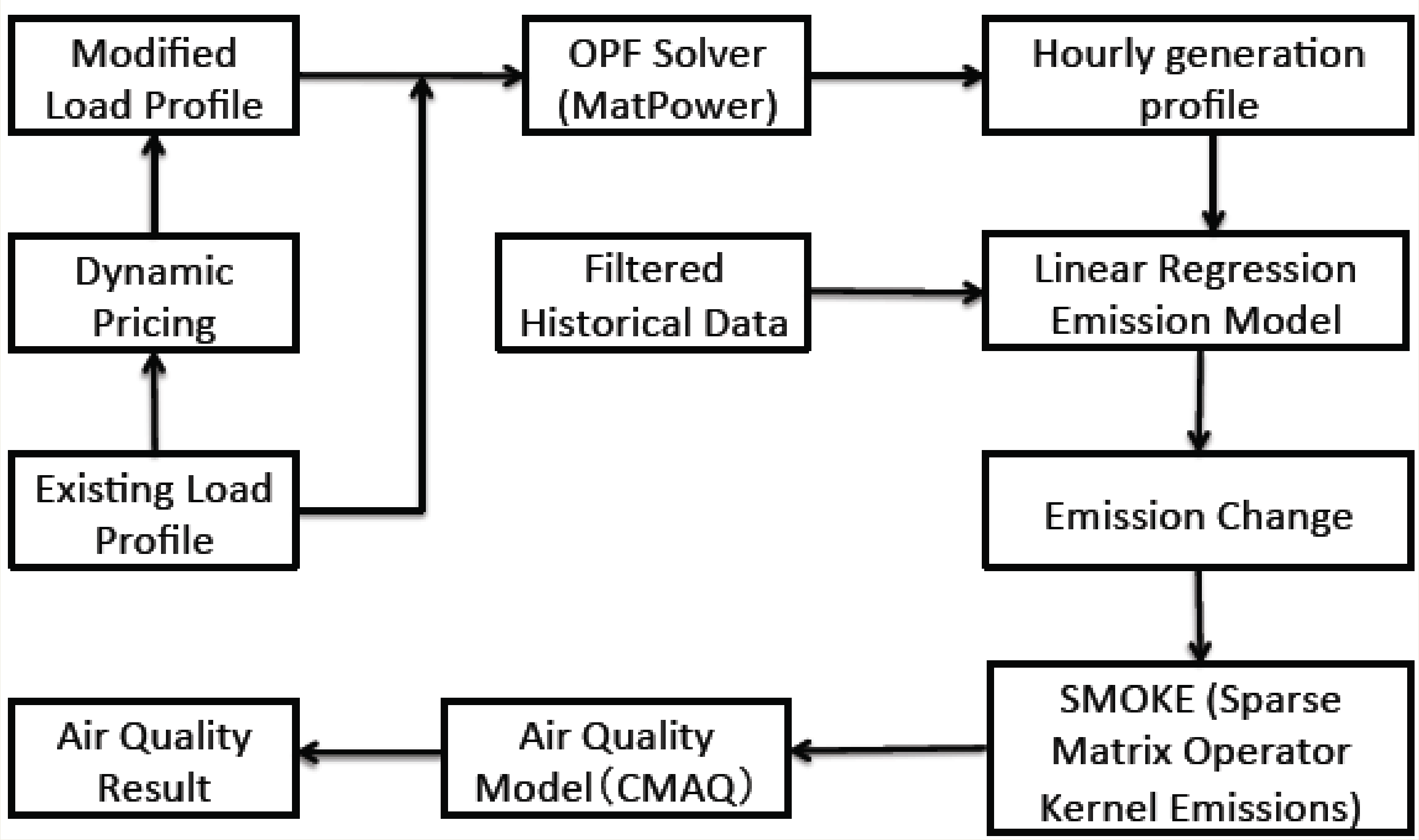

System load
Load
31000
29000
27000
25000
23000
21000
19000
1 3 5 7 9 11 13 15 17 19 21 23
July 9th original load
July 9th DP load


System load
Load
31000
29000
27000
25000
23000
21000
19000
17000
1 3 5 7 9 11 13 15 17 19 21 23
July 12th original load
July 12th DP load


System load
Load
29000
27000
25000
23000
21000
19000
17000
1 3 5 7 9 11 13 15 17 19 21 23
July 15th original load
July 15th DP load

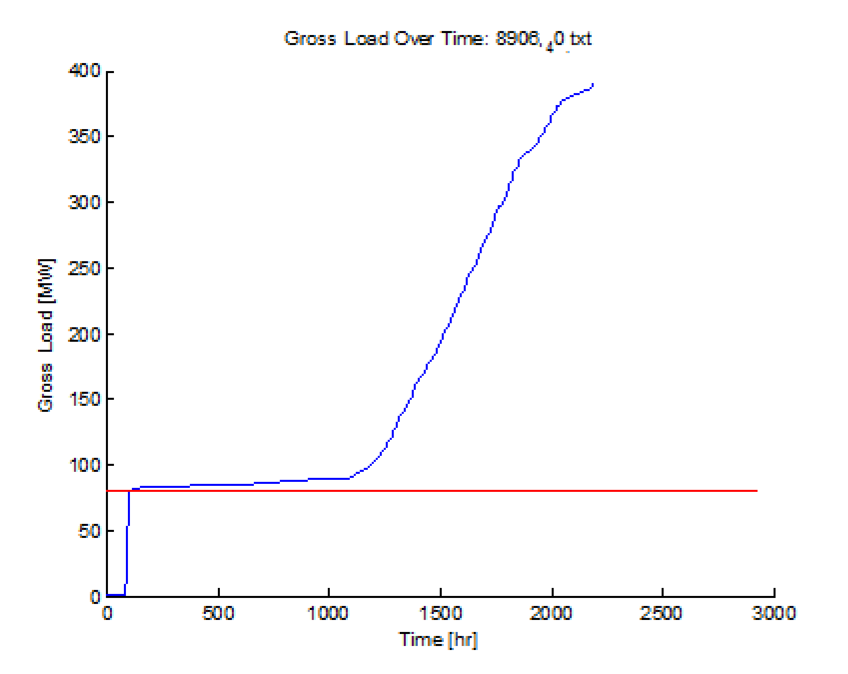

System load
Load
30000
28000
26000
24000
22000
20000
18000
1 3 5 7 9 11 13 15 17 19 21 23
September 3rd original load
September 3rd DP load

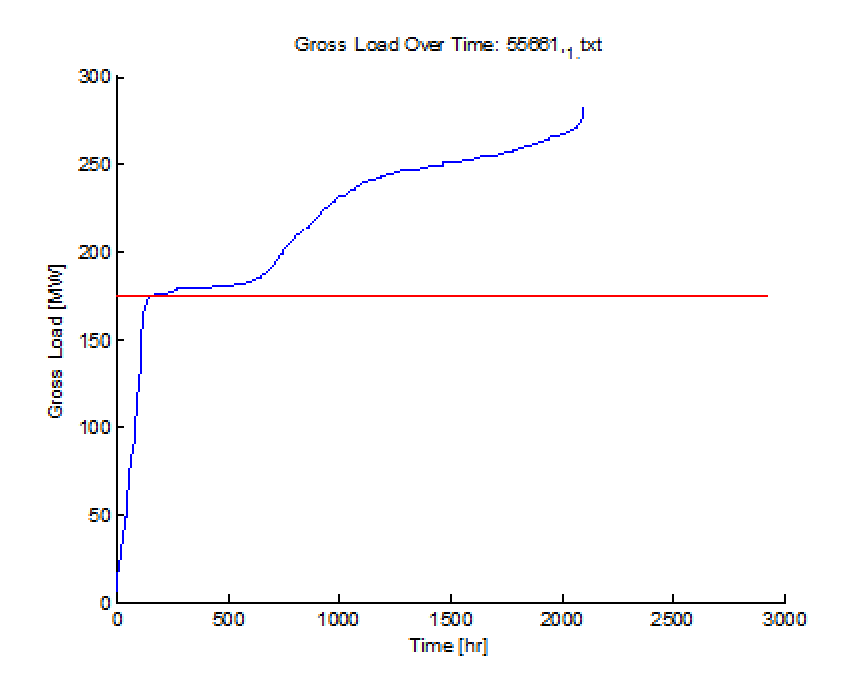
Evaluating Impacts



Emission Predictions: Preprocessing

- 600+ generator data sets (from EPA)
- Filtering: Find minimum generation via greedy deterministic search



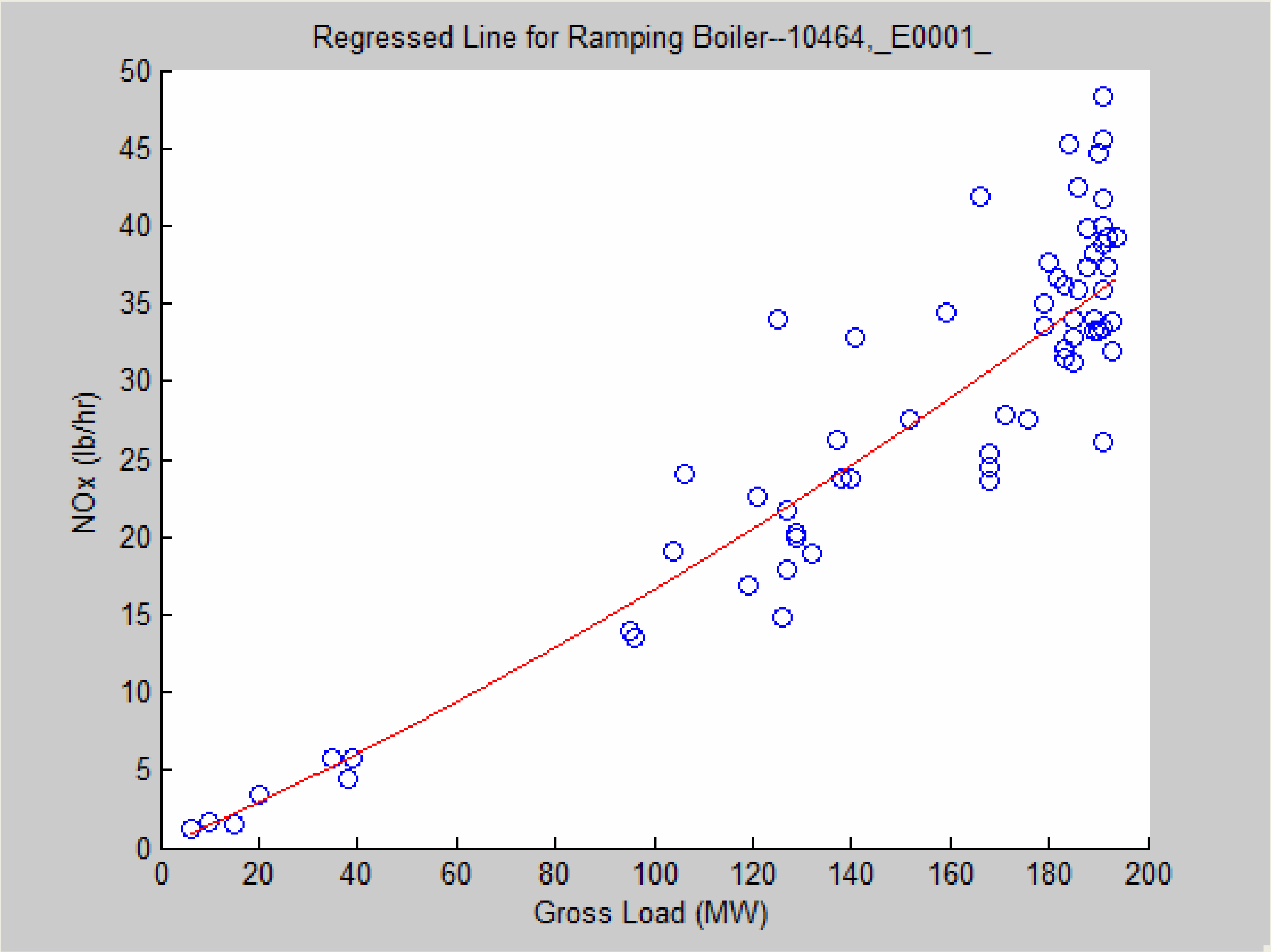


Emission Predictions: 2-Step Regression

- Automated 2nd order regression analysis
- Brute force greedy search to add components

$$\beta_0 + \beta_1 P + \beta_2 P^2 + \beta_3 \Delta P + \beta_4 \Delta P^2 + \beta_5 |\Delta P| + \beta_6 \frac{\Delta P}{P} + \beta_7 \left(\frac{\Delta P}{P}\right)^2 + \beta_8 \frac{|\Delta P|}{P} + \beta_9 P \Delta P$$
$$+ \beta_{10} P |\Delta P| + \beta_{11} \Delta P |\Delta P| + \beta_{12} \frac{\Delta P \Delta P}{P} + \beta_{13} \frac{\Delta P |\Delta P|}{P}$$

- Step 1: Heat Input vs. Gross Load Regression
- Step 2: Emissions vs. Heat Input Regression



Regressed Line for Ramping Boiler--10464,_E0001_
NOx (lb/hr)
Gross Load (MW)
0
5
10
15
20
25
30
35
40
45
50
0
20
40
60
80
100
120
140
160
180
200

Emission Predictions: R^2 Statistics

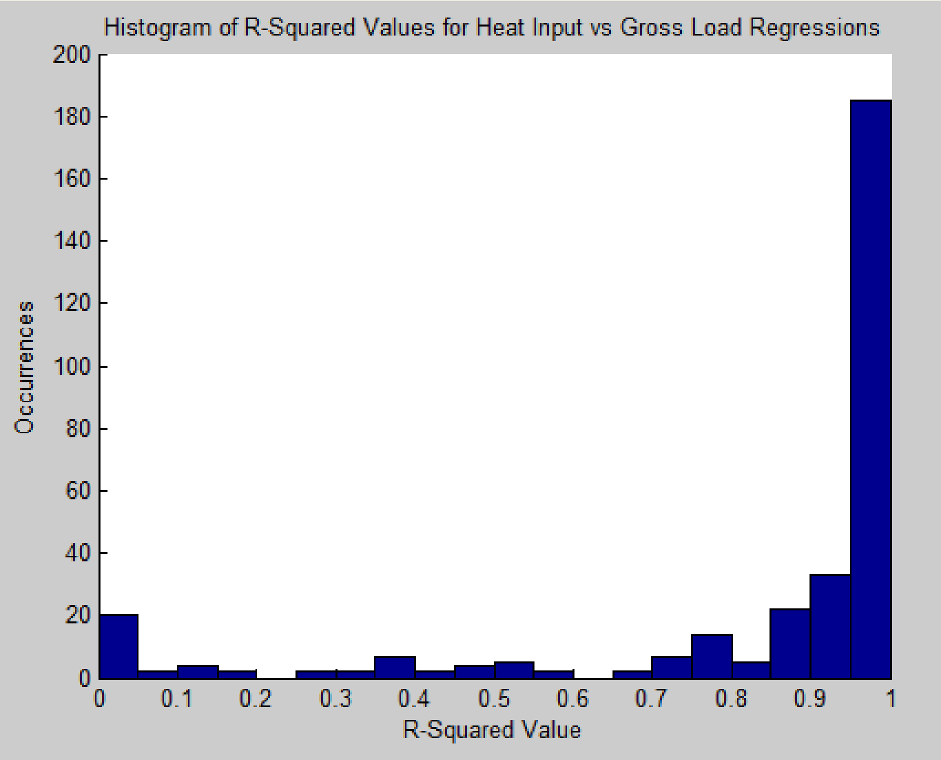
- Define an acceptable R^2 parameter and record the regression for each generator

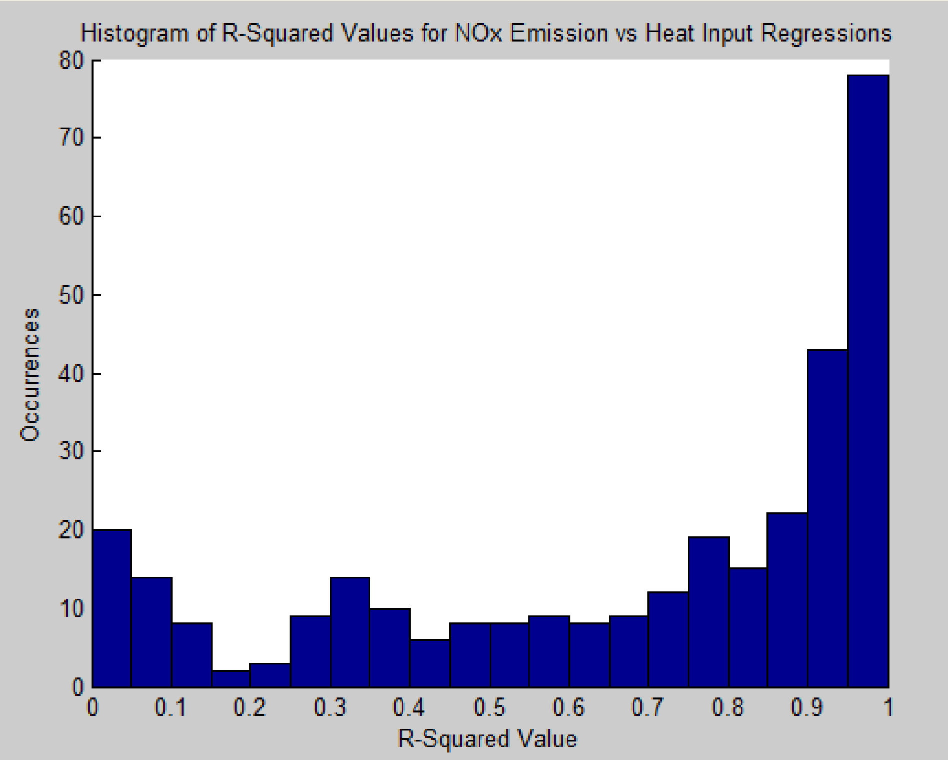
Heat Input vs. Gross Load

Step 1: 73% of datasets with $R^2 > 0.9$
90% of datasets with $R^2 > 0.7$

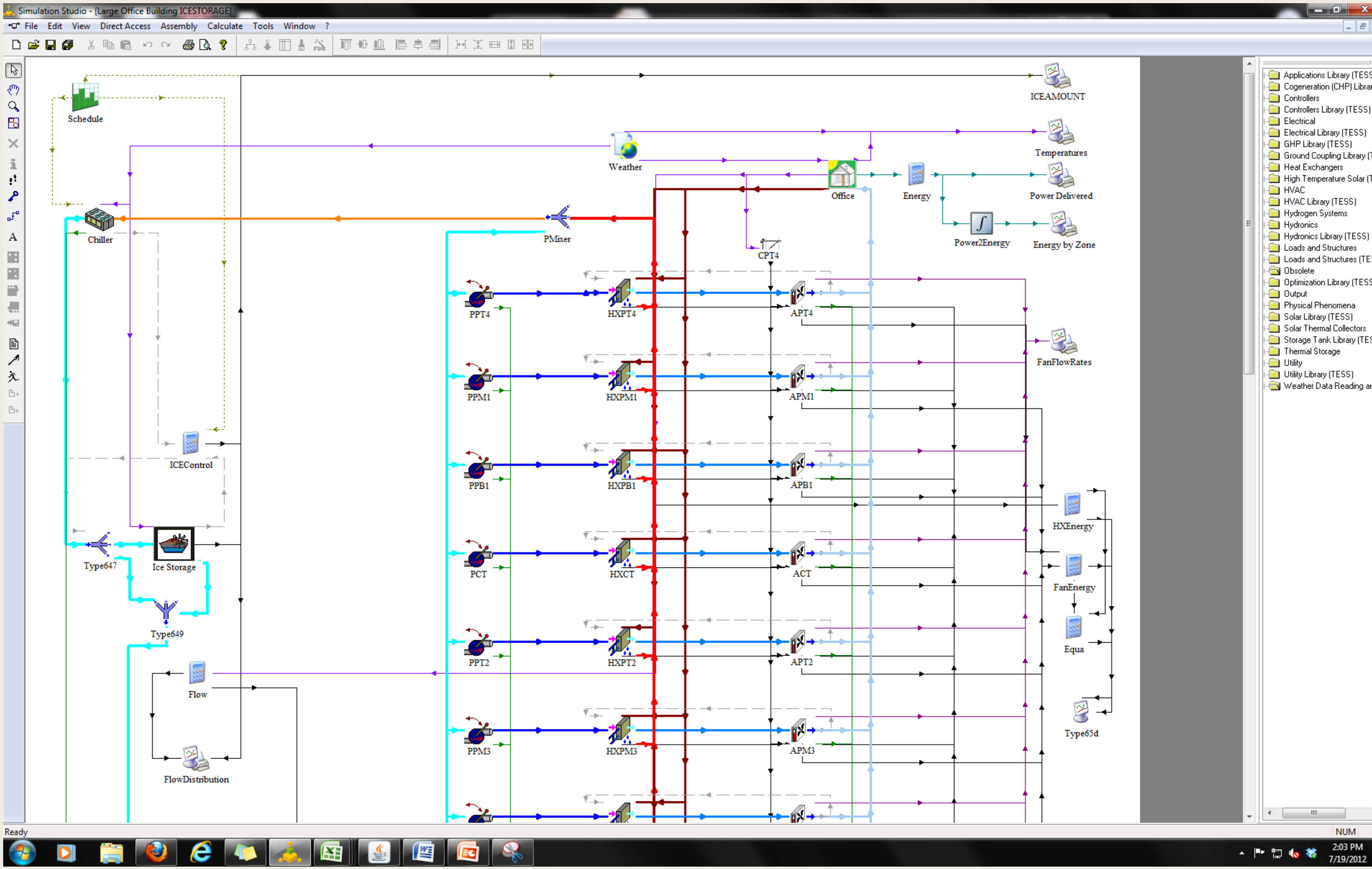
Emissions vs. Heat Input

Step 2: 40% of datasets with $R^2 > 0.9$
64% of datasets with $R^2 > 0.7$





Deriving the efficiency of thermal storage from single building level modeling



Optimize System Costs

Use heuristic methods to allocate cooling loads in order reduce system costs

Day-ahead market Stage

$$\min_{AC_{DAM,t},AC_{RTM,t}}\{\overline{LMP}_{DAM}(\overline{P}_{DAM},|\overline{\Delta P}_{DAM}|)\times\overline{P}_{sys,DAM}+$$
$$E[\overline{LMP}_{RTM}(\overline{P}_{RTM},|\overline{\Delta P}_{ERTM}|)\ \times(\overline{P}_{sys,RTM}-\overline{P}_{sys,DAM})]\}$$

subject to

$$0\le ICEc_{DAM.t}+Lac_{DAM,t}\le MaxChill\quad \forall t\in(0,..,T_1)$$
$$0\le ICEc_{RTM.t}+Lac_{RTM,t}\le MaxChill\quad \forall t\in(0,..,T_1)$$
$$0\le ICEd_{DAM.t}\le MaxDischargeRate\quad \forall t\in(0,..,T_1)$$
$$0\le ICEd_{RTM,t}\le MaxDischargeRate\quad \forall t\in(0,..,T_1)$$

$$0\le \sum_{t=0}^{T_1}(ICEc_{DAM.t}-ICEd_{DAM.t})\le StoreCapacity$$
$$0\le \sum_{t=0}^{T_1}(ICEc_{RTM.t}-ICEd_{RTM.t})\le StoreCapacity$$

$$ICEd_{DAM.t}+Lac_{DAM,t}\le CoolingLoad_t\quad \forall t\in(0,..,T_1)$$
$$ICEd_{RTM.t}+Lac_{RTM,t}=CoolingLoad_t\quad \forall t\in(0,..,T_1)$$

Real-time market Stage

$$\min_{AC_{RTM,t}}\{\overline{LMP}_{DAM}(\overline{P}_{DAM},|\overline{\Delta P}_{DAM}|)\times\overline{P}_{sys,DAM}+$$
$$[\overline{LMP}_{RTM}(\overline{P}_{RTM},|\overline{\Delta P}_{RTM}|)\ \times(\overline{P}_{sys,RTM}-\overline{P}_{sys,DAM})]\}$$

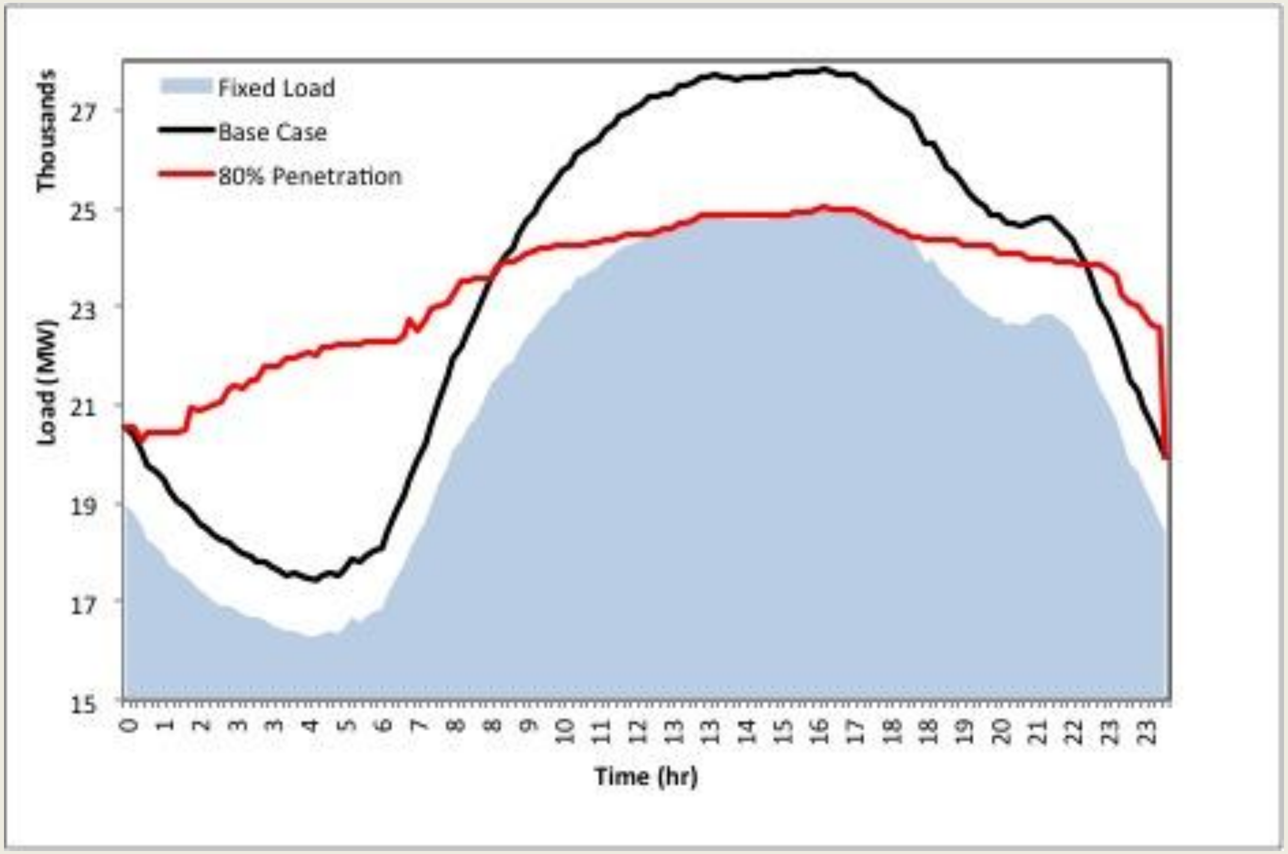
subject to

$$0\le ICEc_{RTM.t}+Lac_{RTM,t}\le MaxChill\quad \forall t\in(0,..,T_1)$$
$$0\le ICEd_{RTM.t}\le MaxDischargeRate\quad \forall t\in(0,..,T_1)$$

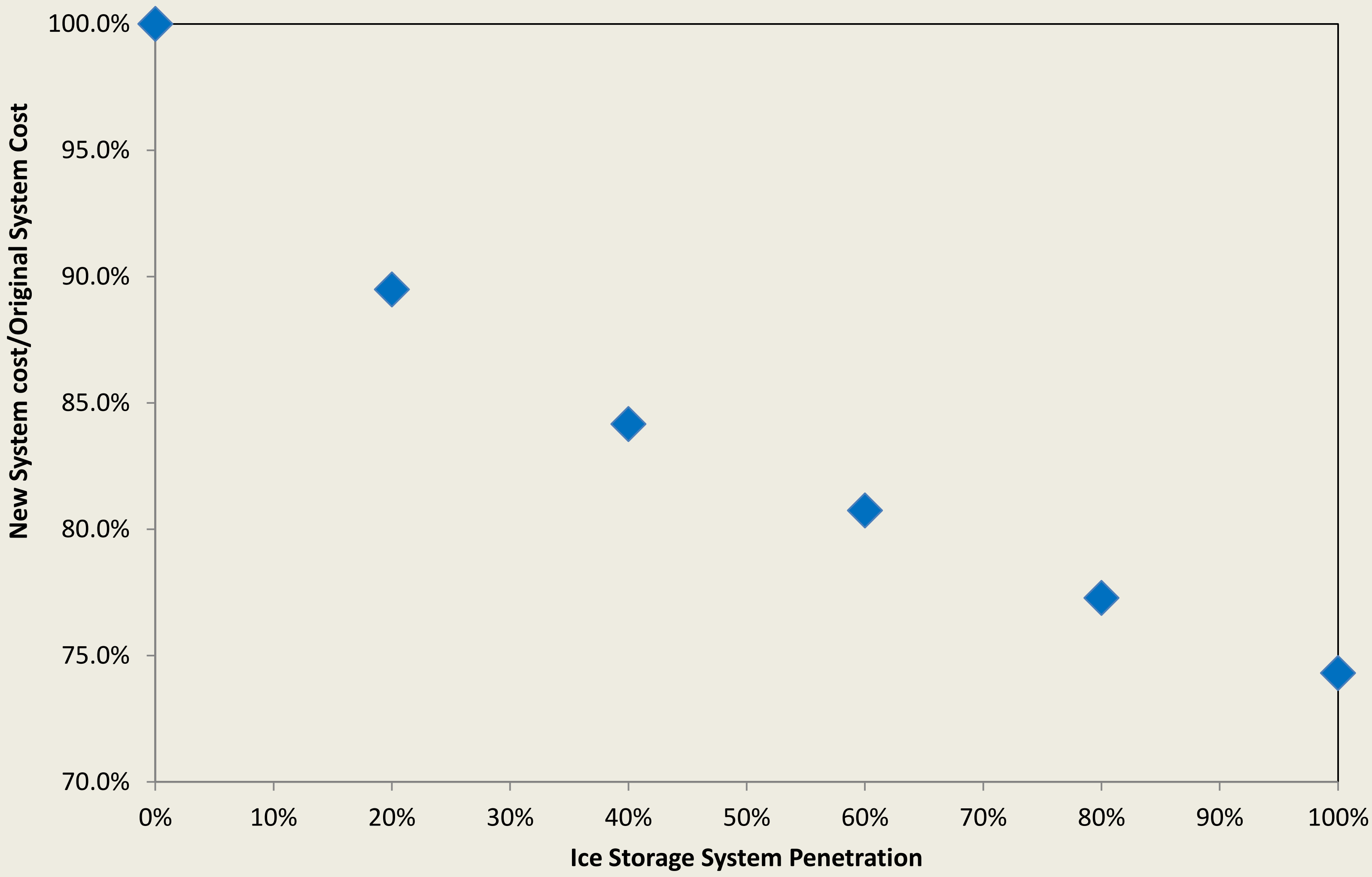
$$0\le \sum_{t=0}^{T_1}(ICEc_{RTM.t}-ICEd_{RTM.t})/6\le StoreCapacity$$

$$ICEd_{RTM.t}+Lac_{RTM,t}=CoolingLoad_t\quad \forall t\in(0,..,T_1)$$

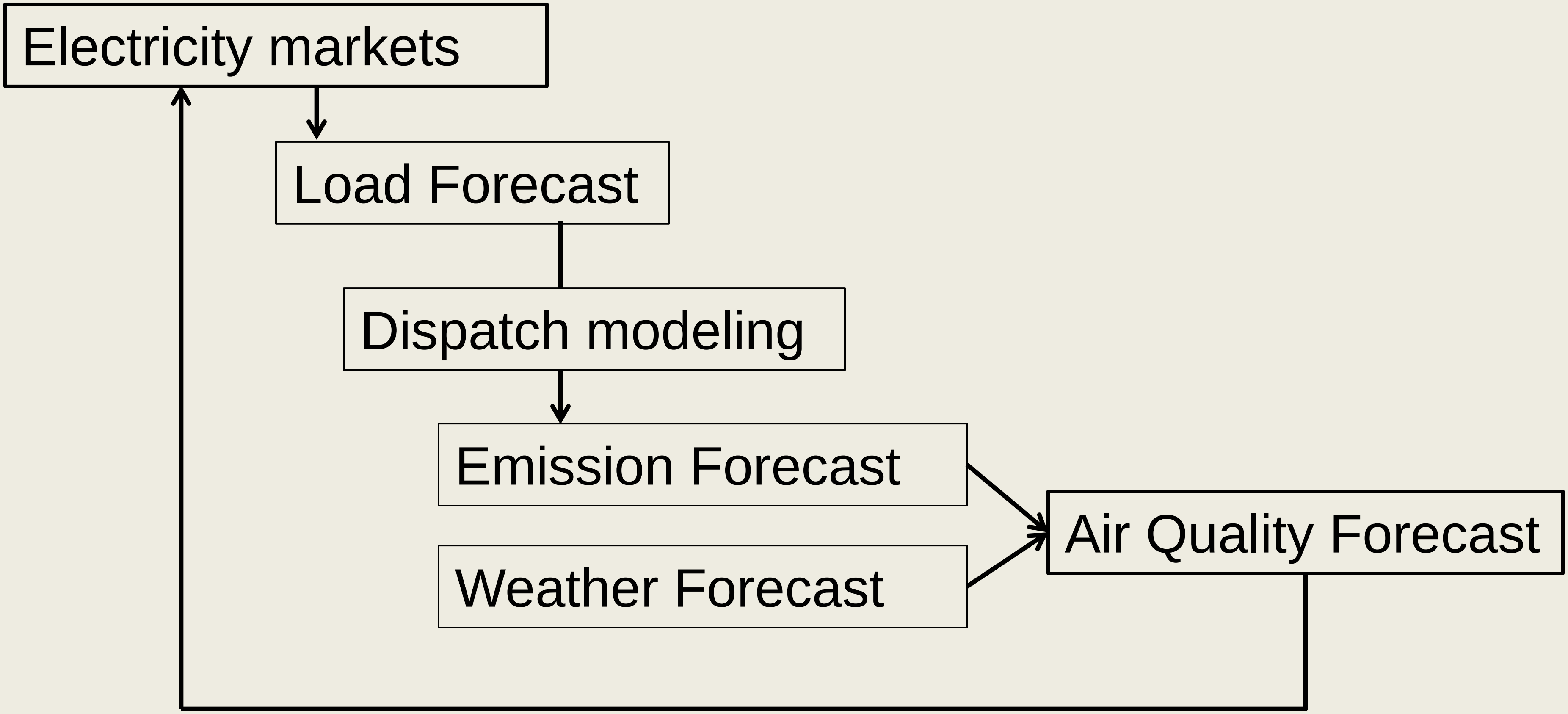
Aggregated thermal storage to reduce system costs in NYCA



System Costs Reduction

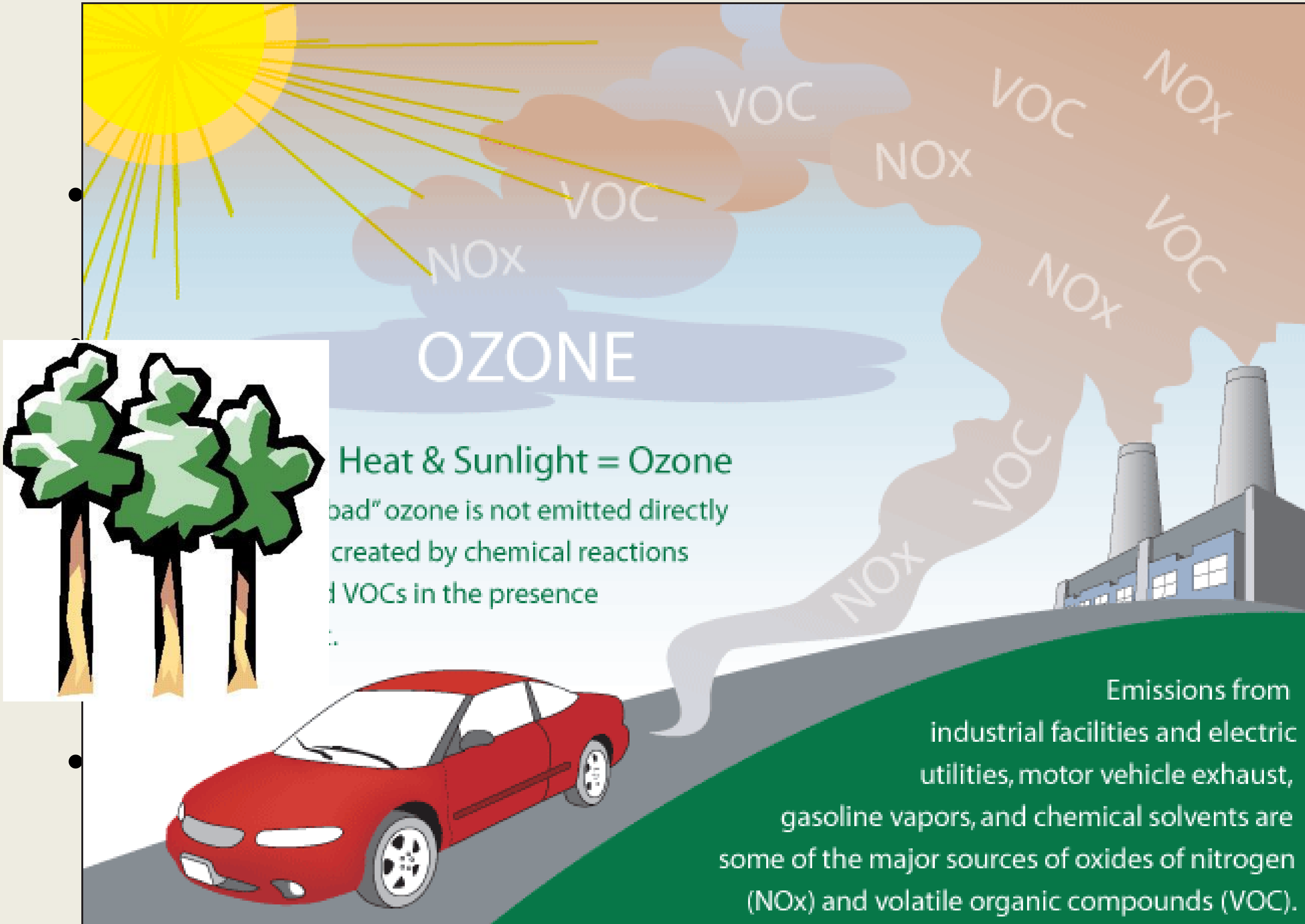


Linking power and environmental systems



Demand-side resources and Extreme Weathers

- Hot temperature: High demand
- Drought: low hydro
- Stagnant condition: Low wind outputs

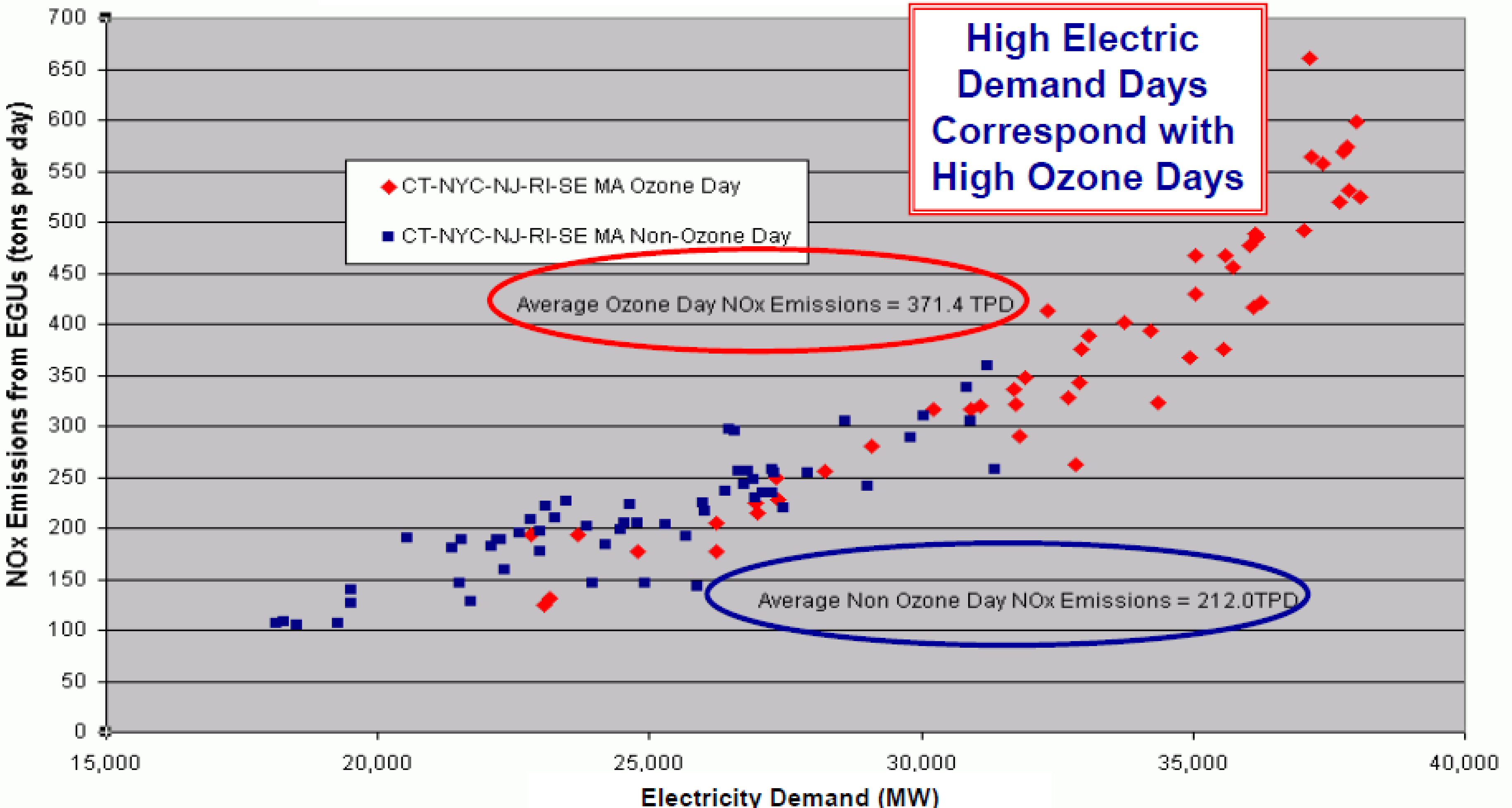


VOC
NOx
VOC
NOx
VOC
NOx
VOC
NOx
OZONE
Heat & Sunlight = Ozone
bad" ozone is not emitted directly
created by chemical reactions
VOCs in the presence
VOC
NOx
Emissions from
industrial facilities and electric
utilities, motor vehicle exhaust,
gasoline vapors, and chemical solvents are
some of the major sources of oxides of nitrogen
(NOx) and volatile organic compounds (VOC).

NO_x Emissions Versus Peak Electricity Demand on Ozone and Non-Ozone Exceedance Days

NJ-NYC-CT-RI-SE MA

(June 1 - September 15, 2002)



Source: EPA Region 1

HEDD Emissions

- HEDD unit operations are a significant contributor to NOx emissions on high ozone days;
- The NOx cap and trade program, although effective generally has, by its very nature, had **limited success** in reducing emissions from HEDD units on HEDDs;
- EPA and State workgroups estimate that using a cap and trade mechanism alone to provide sufficient financial incentives to cause the clean up of HEDD units would need an 18:1 retirement ratio and such a strategy would consume 74% of all available CAIR allowances for 12 HEDD days

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  - Currently the mechanisms for achieving the reductions proposed by air quality regulators emphasize on emission controls of peaking units.
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How can we achieve co-benefits and What need to be considered?

- Electricity markets
  - Critical to ensuring system reliability
  - Require air quality information **in advance**
- Supply and demand
  - Supply: How can we effective dispatch generators to achieve the co-benefits?
  - Demand: A lot of opportunities on the demand-side
    - Demand response
    - Dynamic pricing
    - Price responsive demand

Our Vision for HEDD

- **Supply side**: incorporating air quality forecasting into wholesale day-ahead and real-time electricity markets;
  - dispatching generators taking into account the time- and location-dependent contributions of their NOx emissions to ozone formation (*focus of the first year*)
- **Demand side**: dynamic retail prices of electricity linked to wholesale LBMP
  - incentivize load reduction and
    inductive to ozone formation
  - incentivize the off- peak charg
    penetrate into the automotive
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  - how might environmental con
- **Hypothesis**: the overall costs to th
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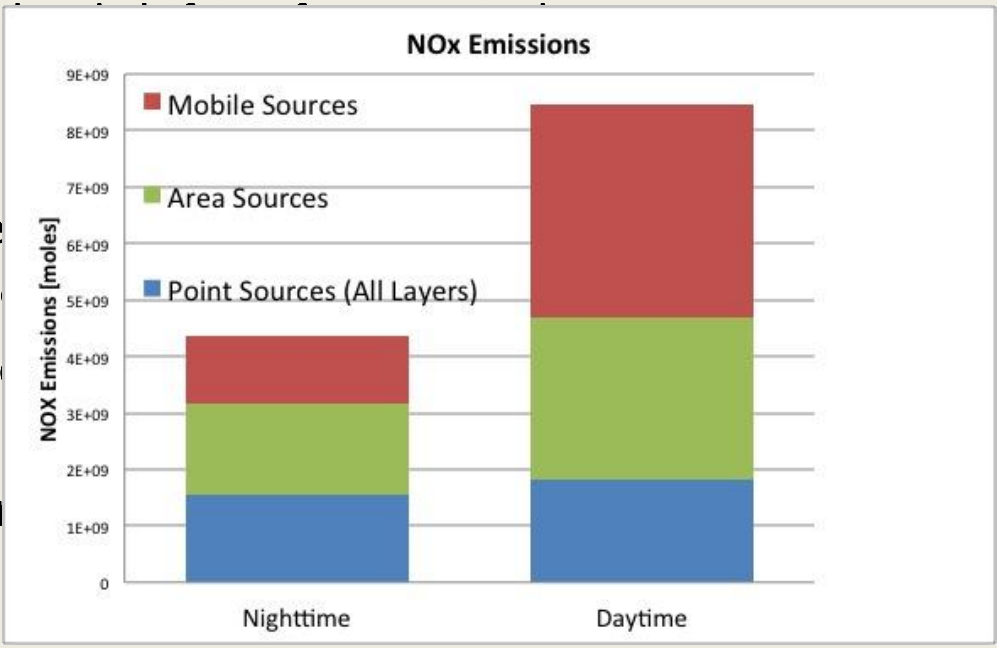
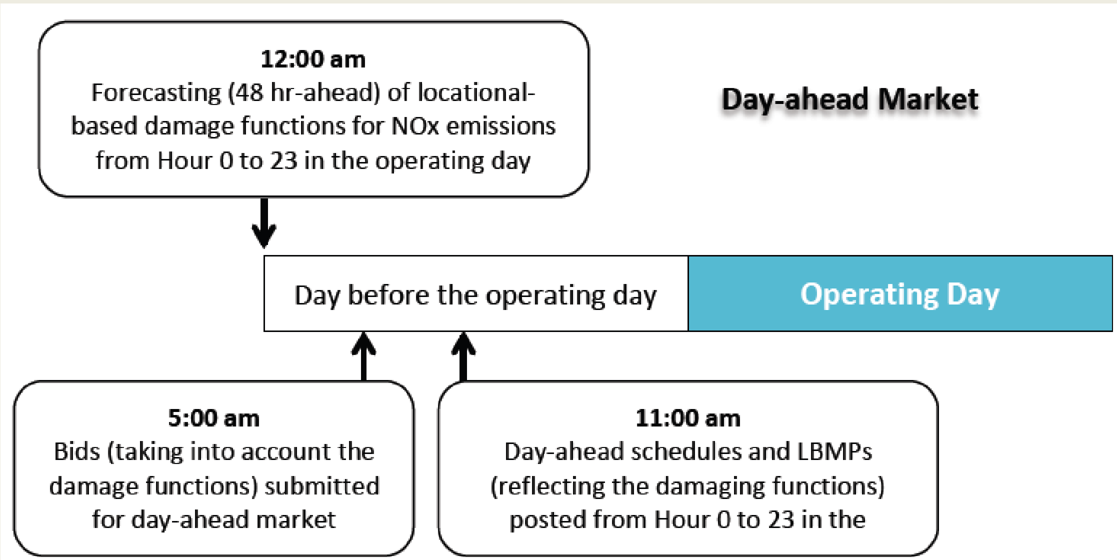
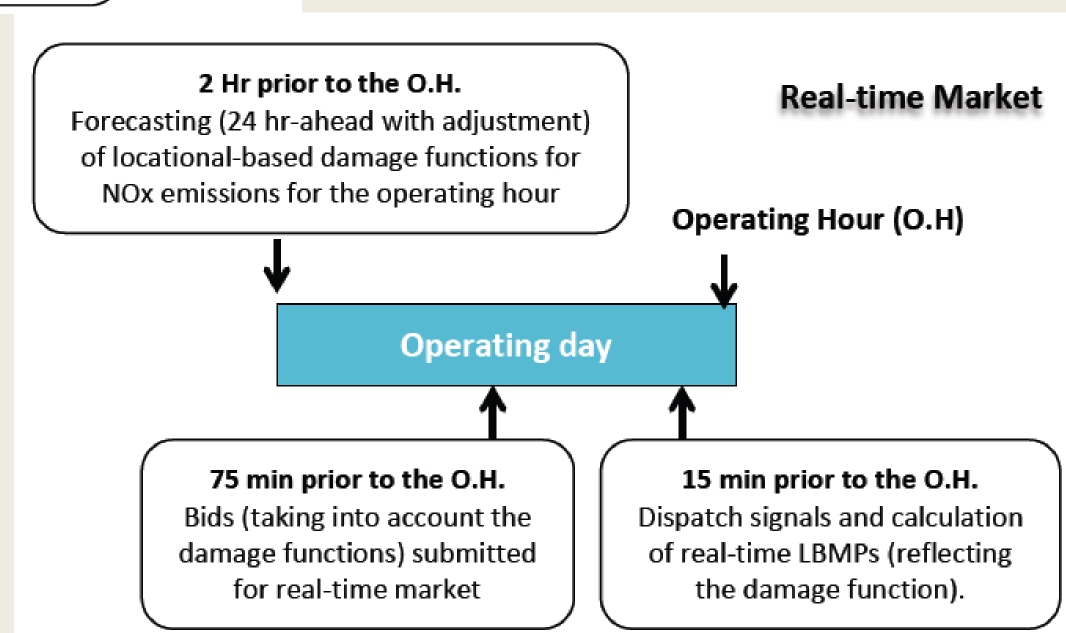


Envisioned Operational Mechanism





Tools

- Power Systems
  - SuperOPF model
  - NPCC network and Eastern Interconnect network
- Air Quality Forecasting
  - National Air Quality Forecasting Capability (NAQFC): operational
  - Decoupled direct method (DDM) to evaluate the contribution of emissions from individual power plants efficiently
  - NAQFC+DDM will forecast the time- and location-dependent (TLD) NOx contributions to ozone formation, which are then employed to quantify the TLD human health costs of NOx emissions
- An very intensive computational problem integrating different components!
- We aim to make the proposed dynamic energy and environmental dispatch operational to have an impact.

Point Sources of NOx Emissions in the U.S. and Canada