The Role of Predictive Models in Energy Efficiency Optimization of Industrial Plants and Buildings

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Outline

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- Energy Efficiency Applications
  - Industrial and building segments
  - Energy supply side / demand side
- Decision Making Scenarios
  - Process industries: refining
  - Cogeneration and buildings
- Energy Demand Forecasting Methods
  - Memory-Based Regression

Energy Efficiency

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- **Terminology**
  - **Energy efficiency = using less energy to provide the same level of service … *e.g. by using more energy efficient appliances***
  - **Energy conservation = using less energy to achieve a lesser energy service … *e.g. through behavioral change***
- **Buildings**
  - **Energy efficient appliances (refrigerators, freezers, ovens, washers, …)**
  - **Monitoring and control of major energy loads (heating, ventilation, air conditioning, lighting, …)**
- **Industry**
  - **Optimized energy conversion – fuel switching, running equipment at its peak efficiency**
  - **Advanced boilers and furnaces (combustion)**
  - **Selection of less energy intensive operating modes**

Energy Efficiency Applications

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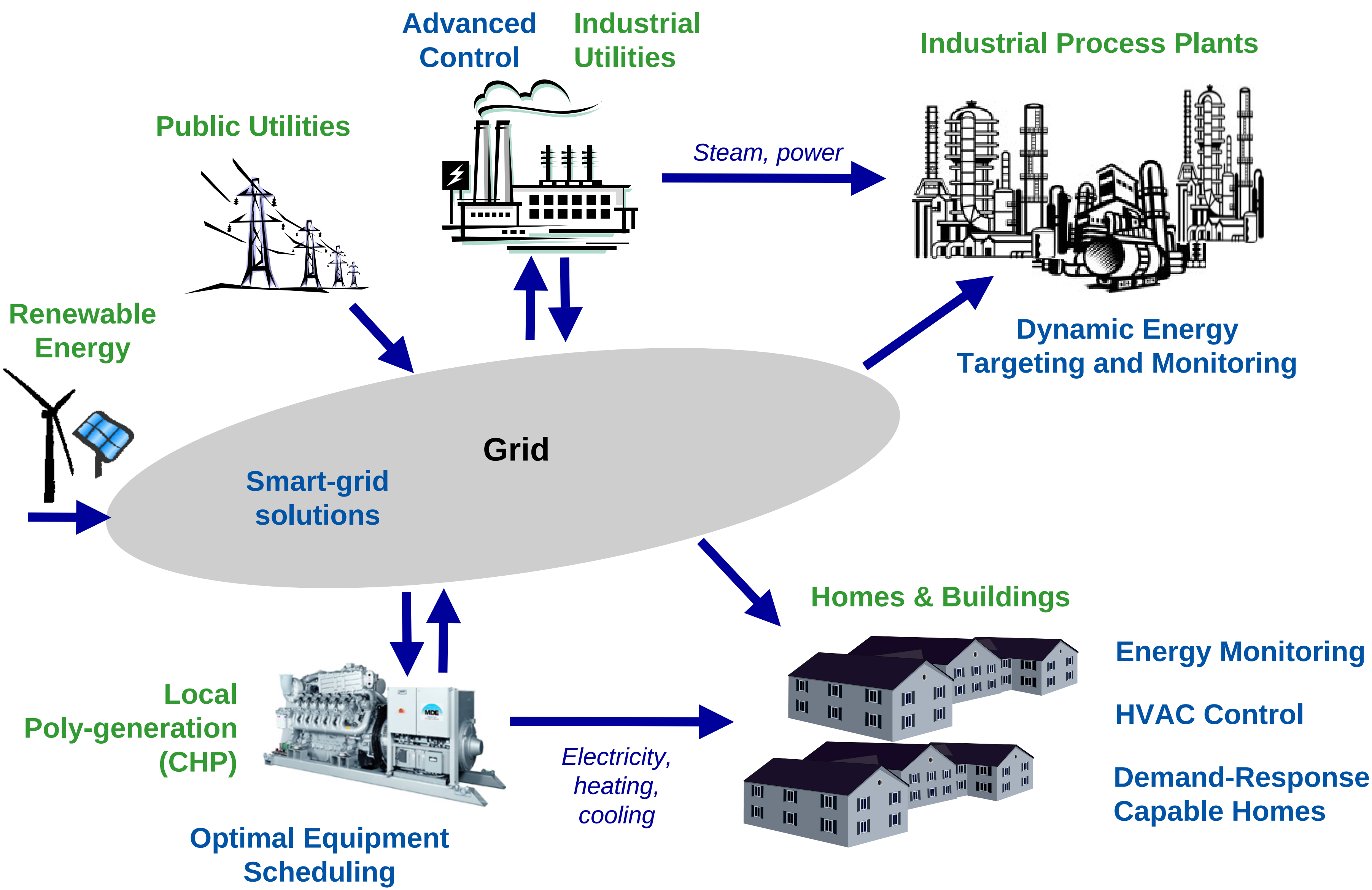

Energy Efficiency Optimization

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	Utility Plants CHP	Process Plants Manufacturing	Buildings Homes
Business objective	Generate utilities (*power, steam, heating, cooling*) to meet customer demands (contracts)	Produce mix of products to meet demands in the downstream industries	Depends on the type of building (*office, hospital, university, army base, shopping center, store, home, etc.*)
Attitude to energy	Energy directly is the primary business objective	Second largest cost (after cost of raw materials)	Differs by the type of activity. Sometimes energy cost is only a fraction of other operating costs
Energy efficiency	Consistently addressed in the plants	Minimize energy use but delivery of products is the first priority	Minimize energy use but keeping occupants comfort is the first priority
Approach	Closed-loop control Hierarchical optimization	Dynamic targeting Continuous improvement	Energy monitoring Continuous improvement
Energy Demand		Dominated by production schedule	Dominated by occupants needs

Oil Refinery

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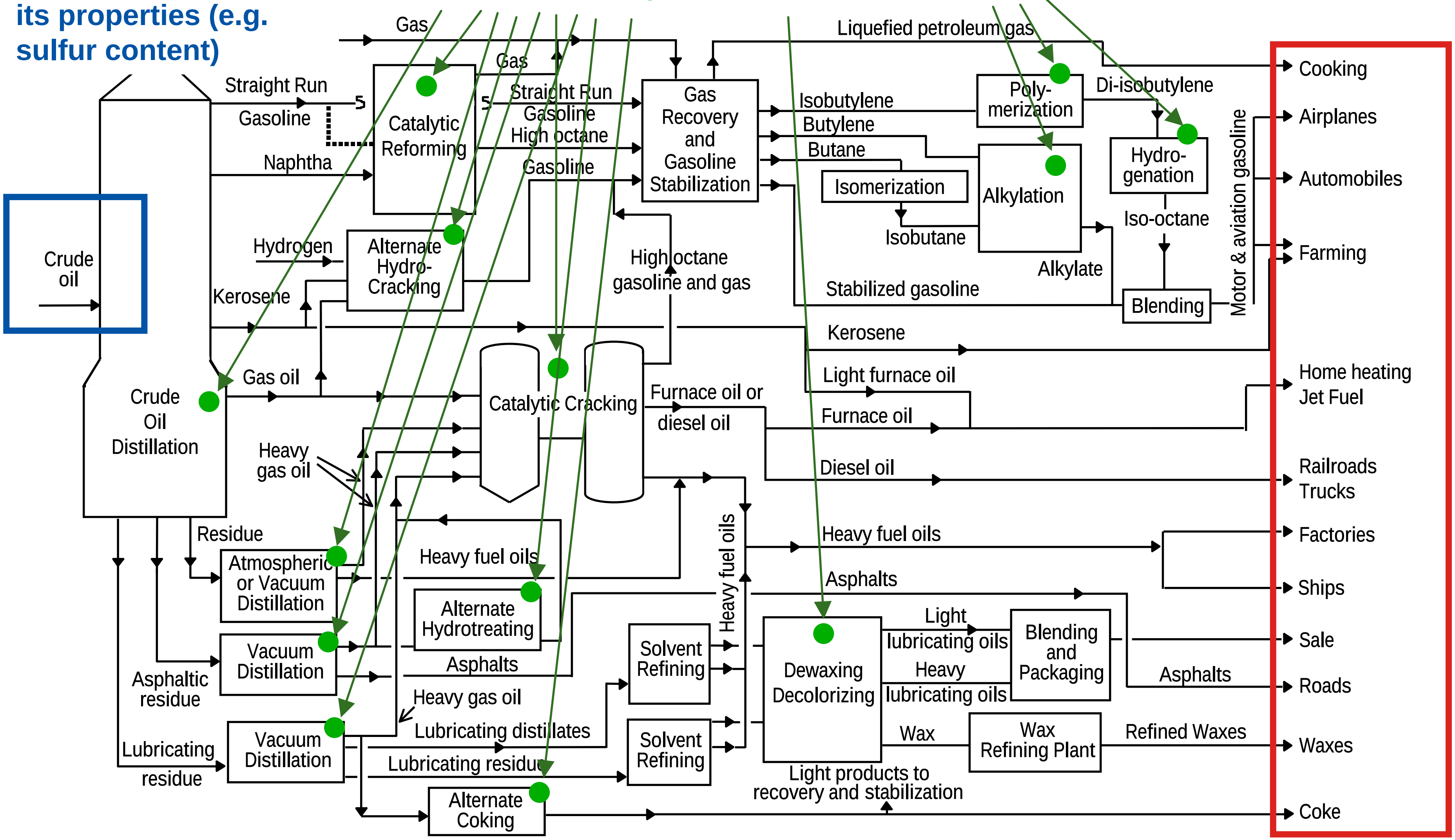
Operation is mostly determined by the specific crude oil and its properties (e.g. sulfur content)

Minimizing energy use and environmental impact by selecting less energy intensive modes on each process unit

Mix of products to be produced to meet orders



Plant-Wide Optimization Criterion

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- **<u>Plant profit</u> can be formulated as:**

$$\text{Plant Profit} = +\sum\left(\begin{matrix}\text{Product}\\\text{rate}\end{matrix} * \begin{matrix}\text{Product}\\\text{value}\end{matrix}\right)$$

$$-\sum\left(\begin{matrix}\text{Raw}\\\text{material}\\\text{usage}\end{matrix} * \begin{matrix}\text{Raw}\\\text{material}\\\text{cost}\end{matrix}\right)$$

$$-\sum\left(\begin{matrix}\text{Utility}\\\text{consumption}\end{matrix} * \begin{matrix}\text{Utility}\\\text{value}\end{matrix}\right)$$

- Maintenance costs

- Penalties for GHG emissions

- other costs

<u>Utility consumption</u> can be estimated potentially for each unit based on the previously built model that relates energy consumption with capacity utilization, operating modes, etc.

Closely related to on-site energy generation, types of fuels used, overall energy efficiency, etc.

Predictive Model for Crude Distillation Unit

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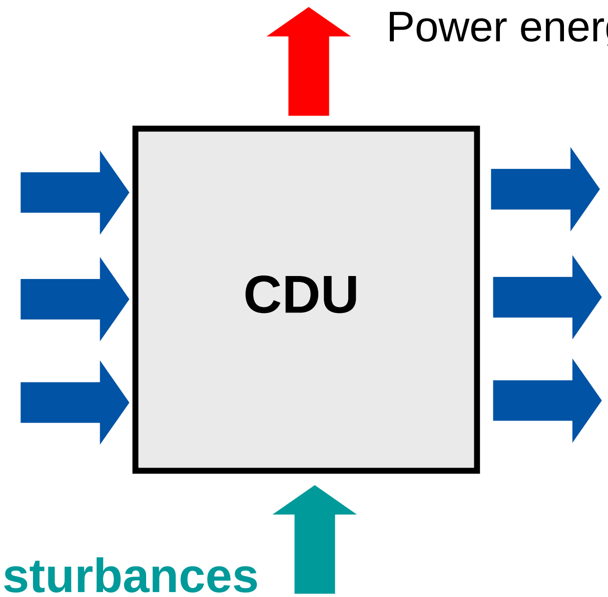
- **Correlates energy consumption on CDU unit with <u>production targets</u> that uniquely define the mode of operation**



CHP and Buildings

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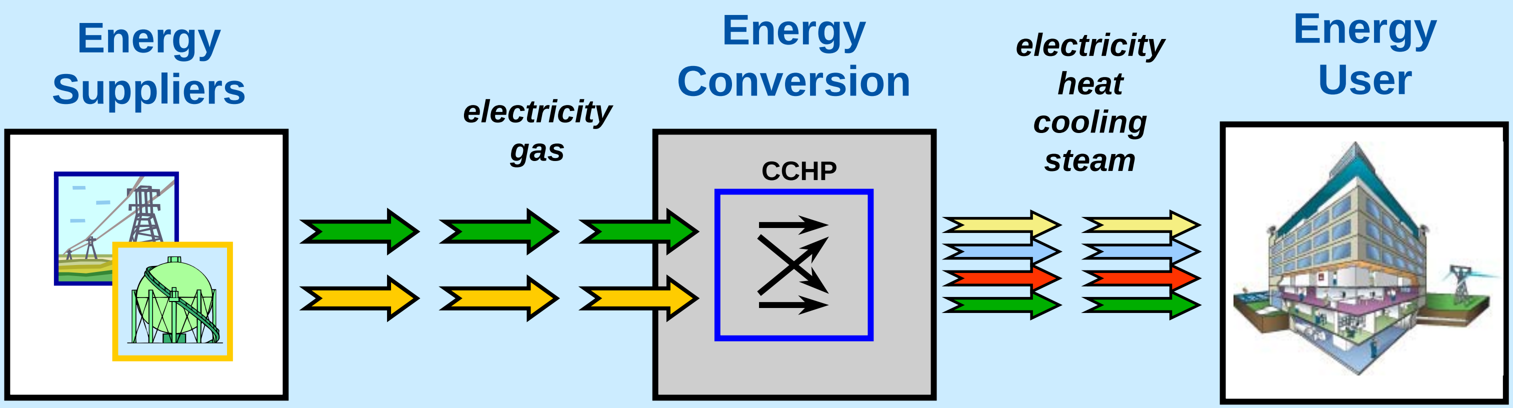

Real time pricing

Variable efficiency

Fluctuating demand

- **Conversion efficiency of the CHP system is optimized**
  - *Gas turbines, steam turbines, steam boilers, hot water boilers, compressor chillers, absorption chillers*

- **Energy demand primarily depends on**
  - **People's behavior** – *How many occupants are in the building? What they are doing?*
  - **Weather** – *Do we need cooling or heating? How much is needed to keep the adequate comfort level?*

Various Daily Profiles …

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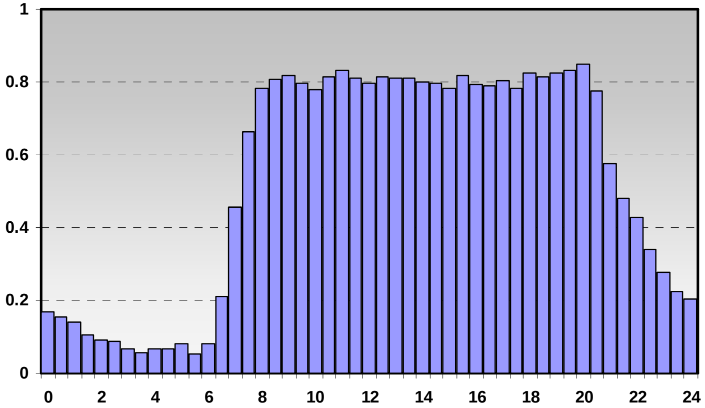
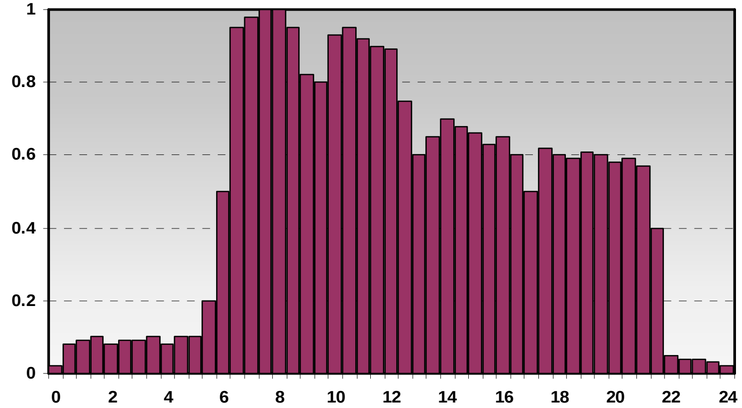
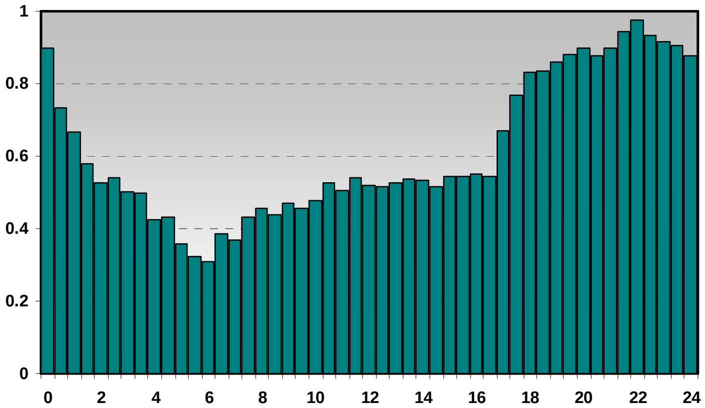
Daily Consumption Profiles



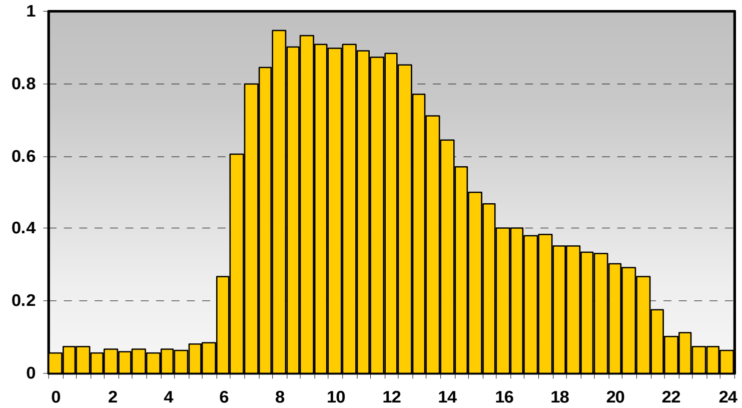
… commerce



… two-shift manufacturing



… casino



… administration

Structure of the Predictive Model

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Inputs

Data age
Time of day
Holiday
Ambient temperature
Wind velocity
Humidity

Demand Model

Predictions

Heating demand
Cooling demand
Electricity demand
Steam demand
…

Accuracy of energy demand predictions depends heavily on accuracy of weather forecasts

Energy Demand Modeling Techniques

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- **Heuristics and benchmarks**
  - **“Rule of thumb”, benchmarking of similar units**
- **First principle models**
  - **Based on thermodynamics, mass and energy balances**
- **Time series models**
  - **ARMA with exogenous variables (e.g. outdoor temperature)**
- **Statistical regression**
  - **Basic regression functions are determined based on the knowledge how the manufacturing plant is operated**
  - **Resulting “global” models need to be regularly updated**
  - **Linear regression, Partial Least Squares (PLS)**
- **Local regression**
  - **Regression models are built based on understanding of variations and correlations in historical data**
  - **Local modeling deals well with non-linear dependencies, and with segmentation of data in clusters**
  - **Also known as: *memory-based regression, locally weighted regression (non-parametric statistics)***

Local Modeling

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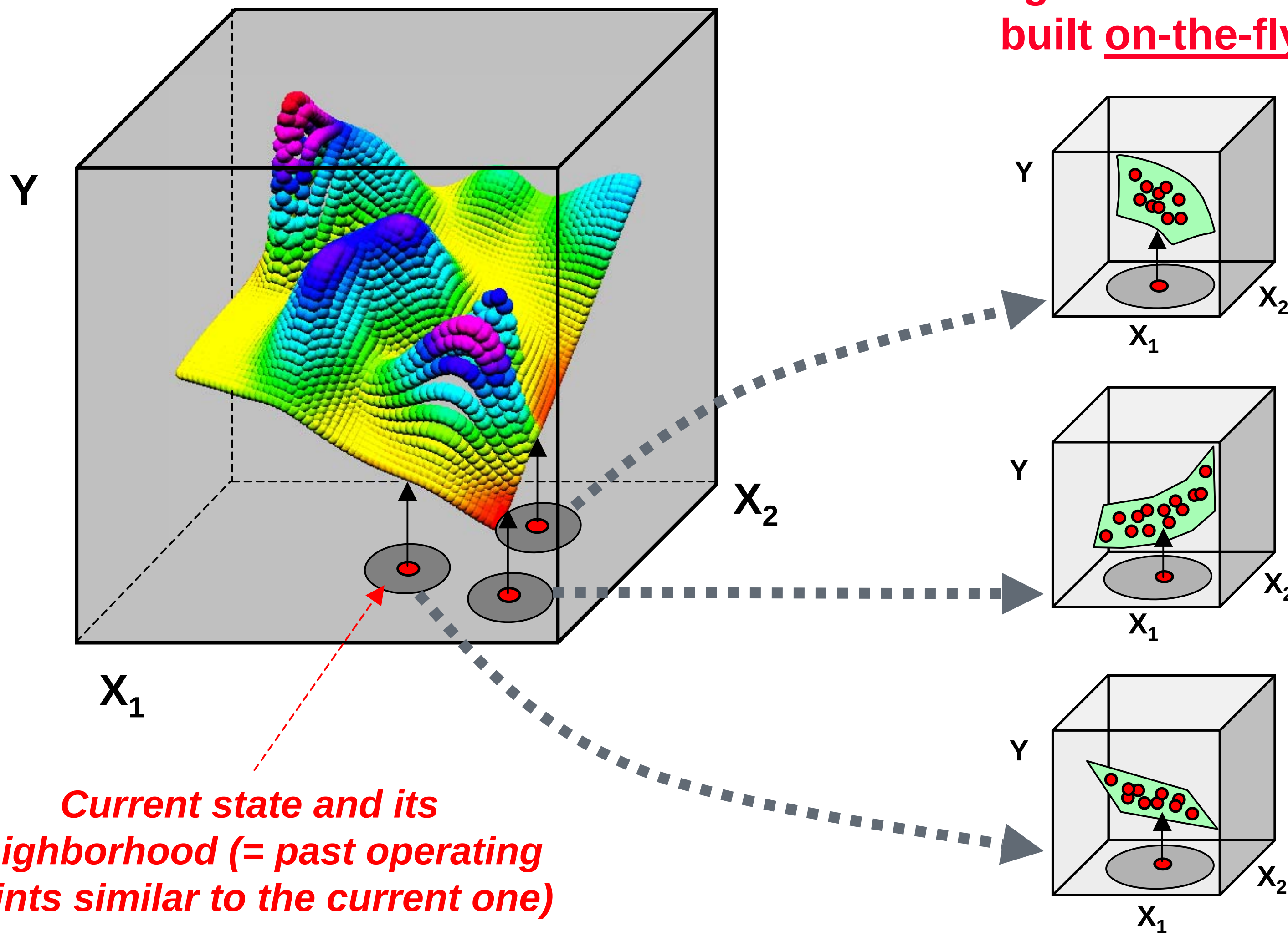
Local regression models are built <u>on-the-fly</u>



Current state and its neighborhood (= past operating points similar to the current one)

… the dependency $Y=f(X_1,X_2)$ is much simpler in the local neighborhood than in global context

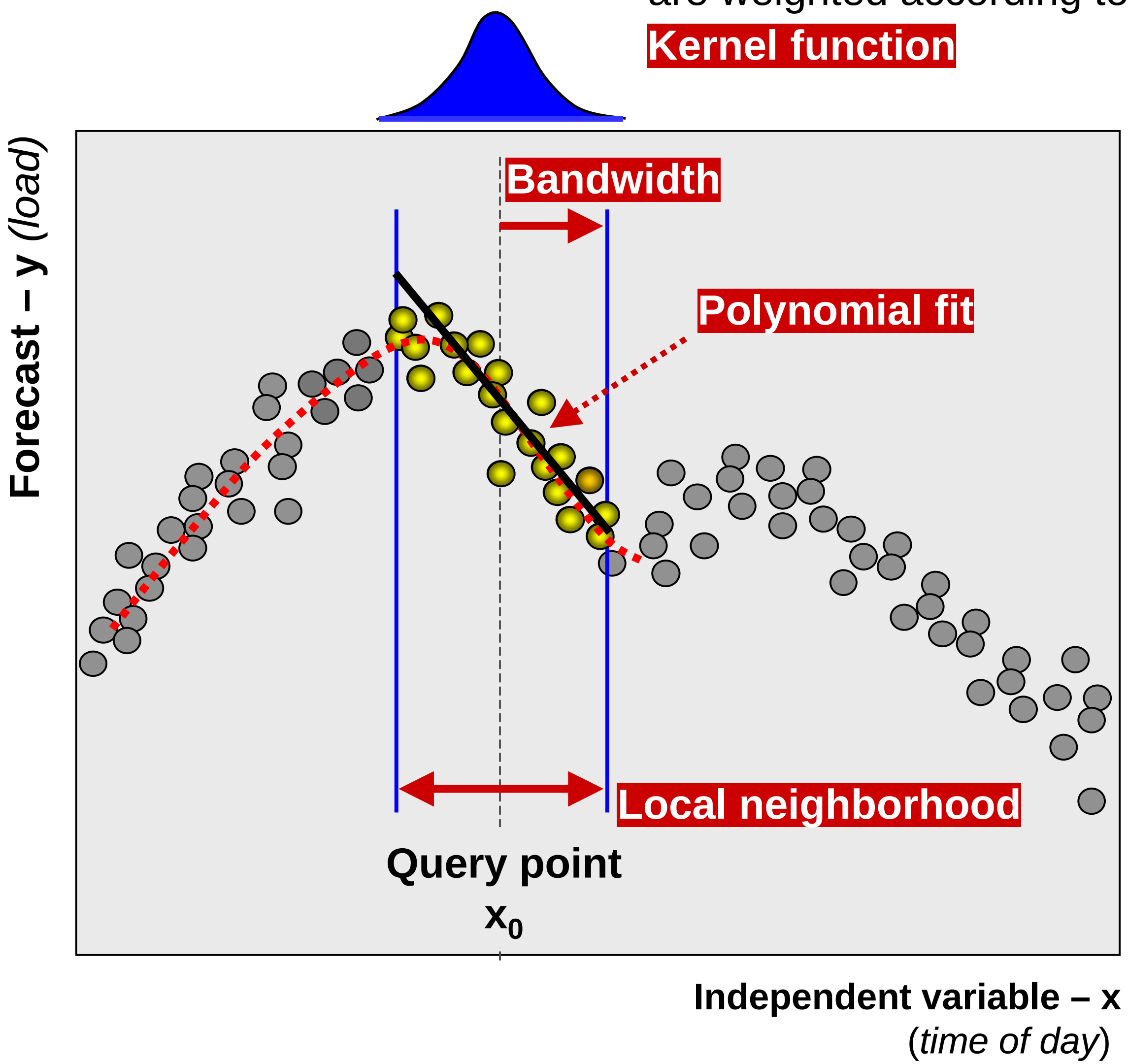
Local Regression

Points in the neighborhood are weighted according to **Kernel function**

$$w = \exp\left(\frac{-3\sigma\, d^2}{2}\right)$$

Distance function

$$d^2 = \sum_{i=1}^{N}\left(\frac{X_i^* - X_i}{h_i}\right)^2$$



Forecasting Results

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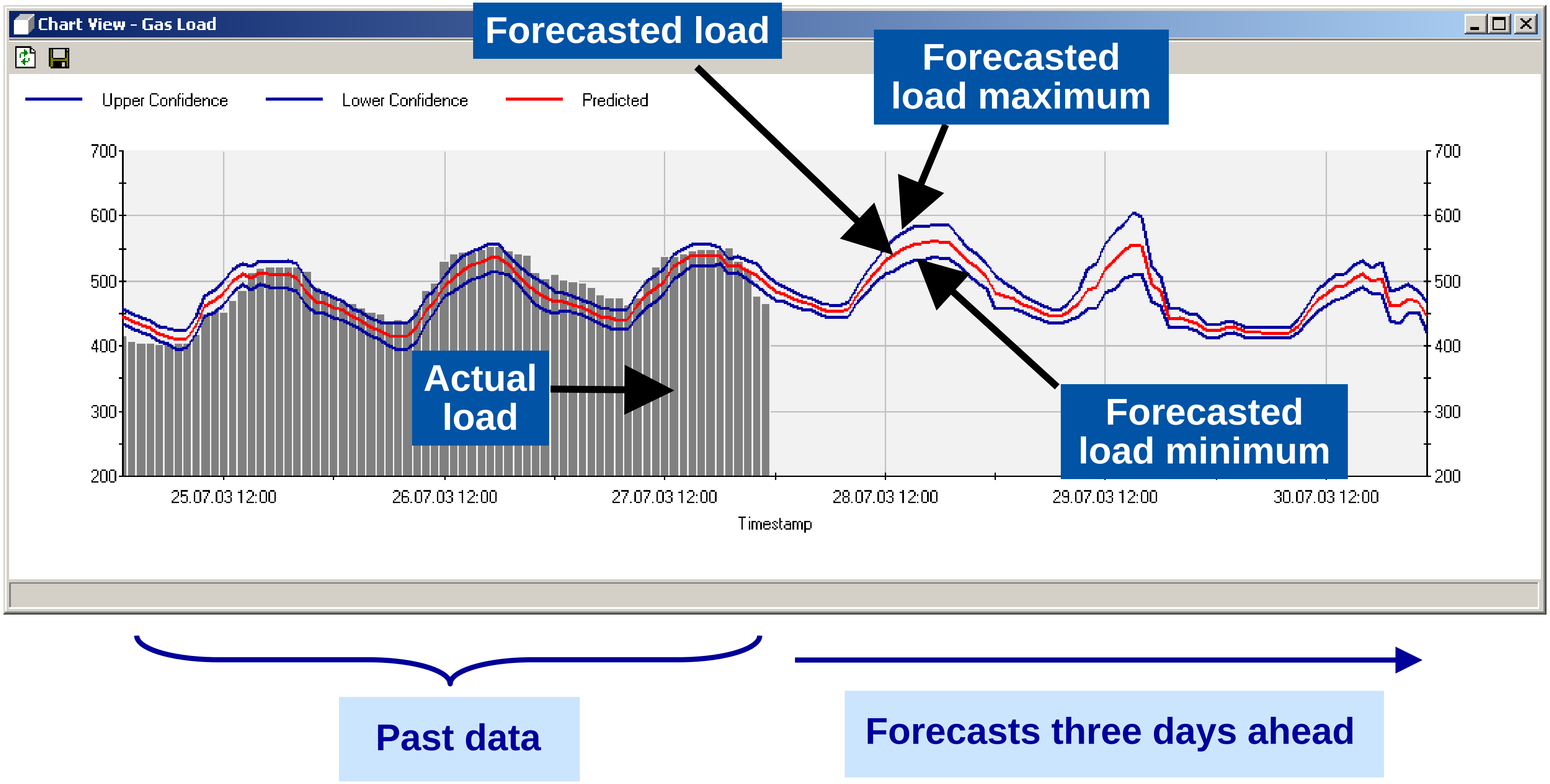

Thank you for your attention!