Introduction

Quantitative Energy Economics

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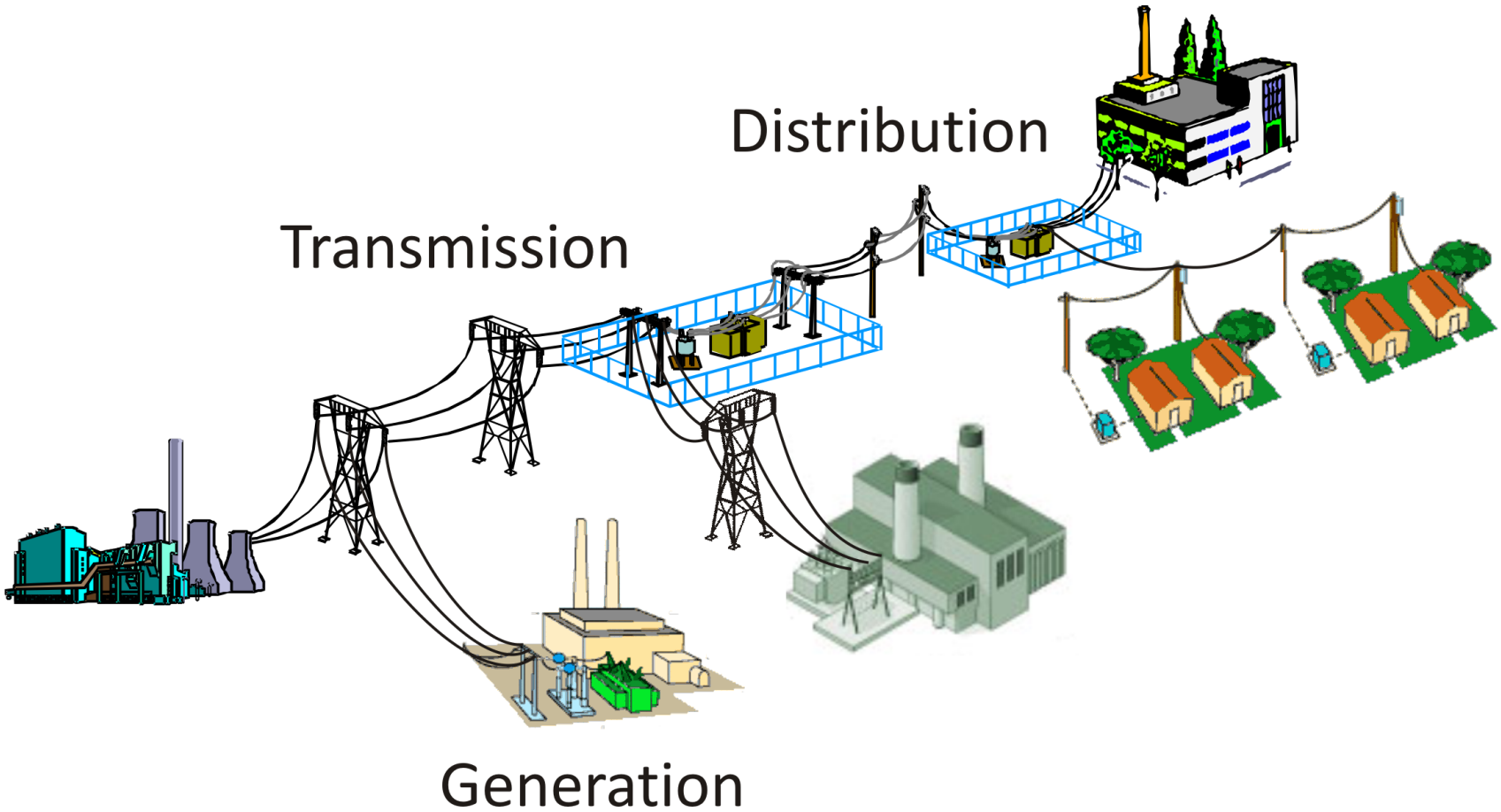
Contents

Paradigm Shift

Operations research more important than ever in energy

- Policy changes
  - Deregulation
  - Renewable energy integration
- Technology changes
  - Evolution of solvers
  - Parallel computing

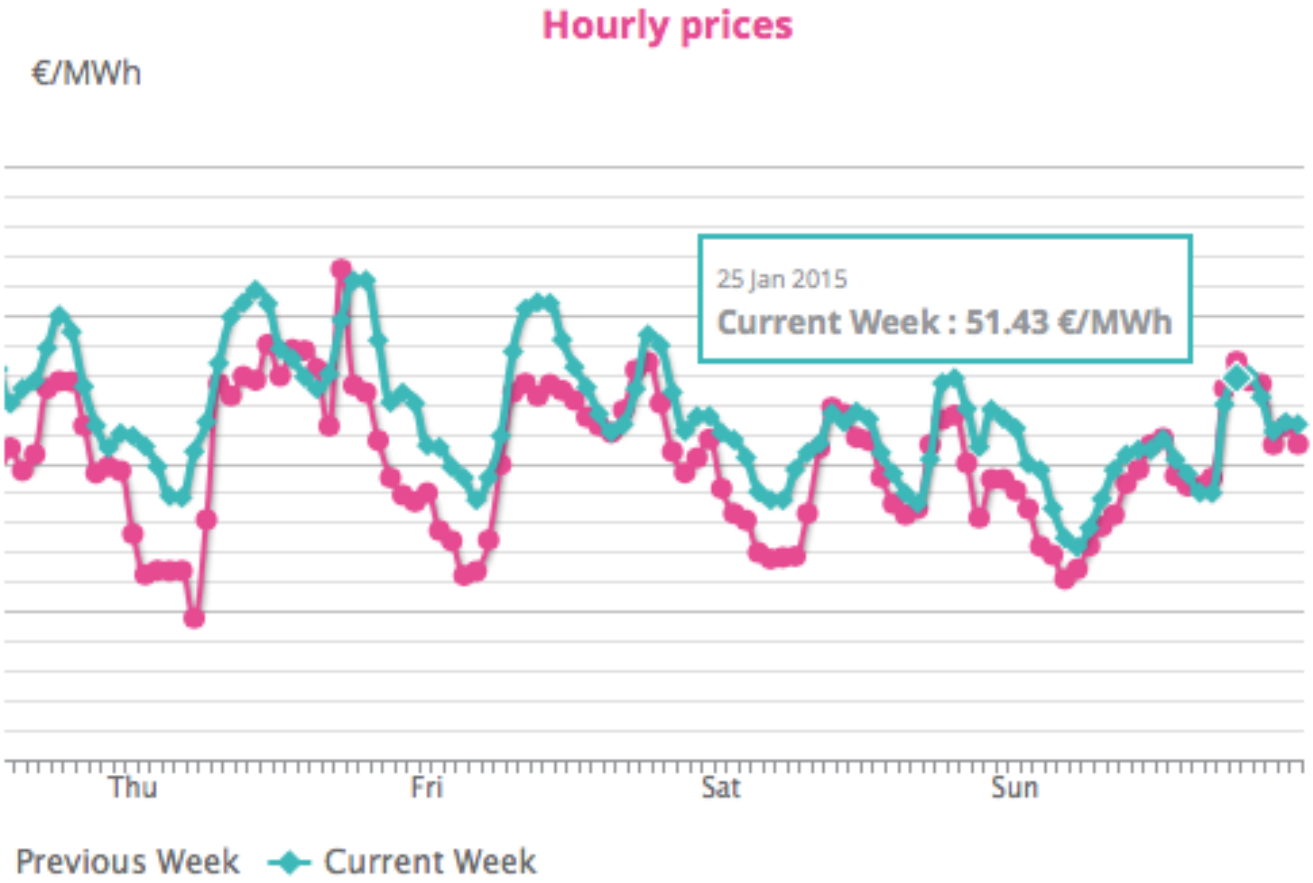
Electricity Supply Chain



The integrated operation of the electricity supply chain ...

Deregulation

... has been replaced by a market



Electricity price in Belgium, January 18-25, 2015

Renewables Making Headlines

BBC News Sport Weather Capital Culture

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30 May 2011 Last updated at 12:25 GMT

16K Share

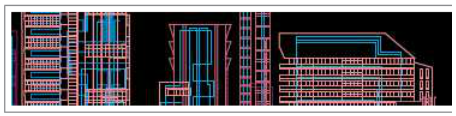
Germany: Nuclear power plants to close by 2022

COMMENTS (542)

Germany saw mass anti-nuclear protests in the wake of the Fukushima disaster

REUTERS EDITION: U.S.

Home Business Markets World Politics Tech Opinion



Denmark aims for 100 percent renewable energy in 2050

BY METTE FRAENDE

COPENHAGEN | Fri Nov 25, 2011 11:49am EST

REUTERS EDITION: U.S. Register

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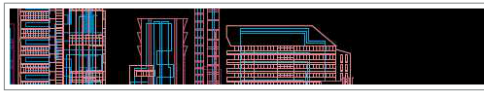
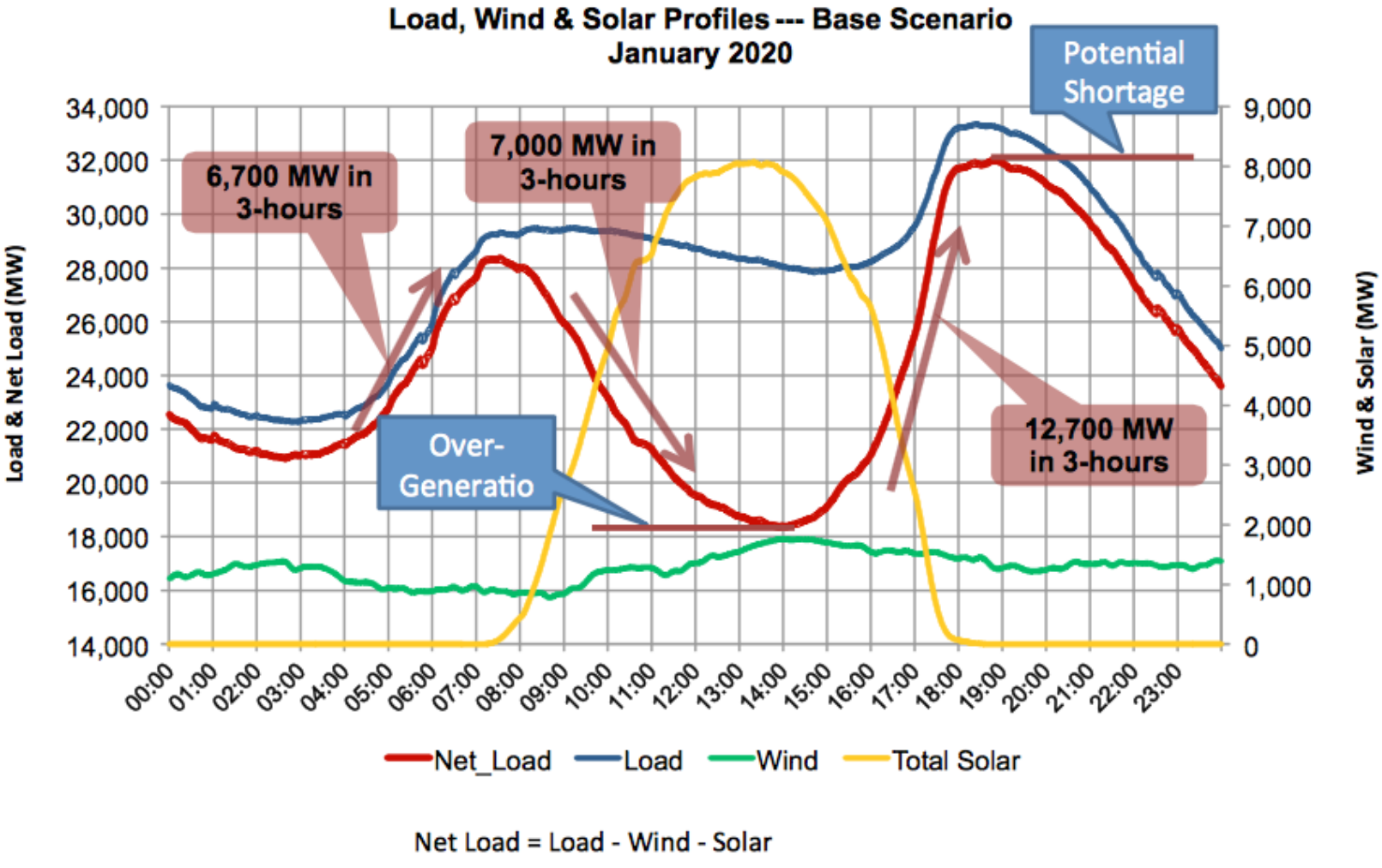


California to nearly double wind, solar energy output by 2020 -regulator

Thu Nov 14, 2013 1:30pm EST

The Duck Chart



Evolution of Solvers

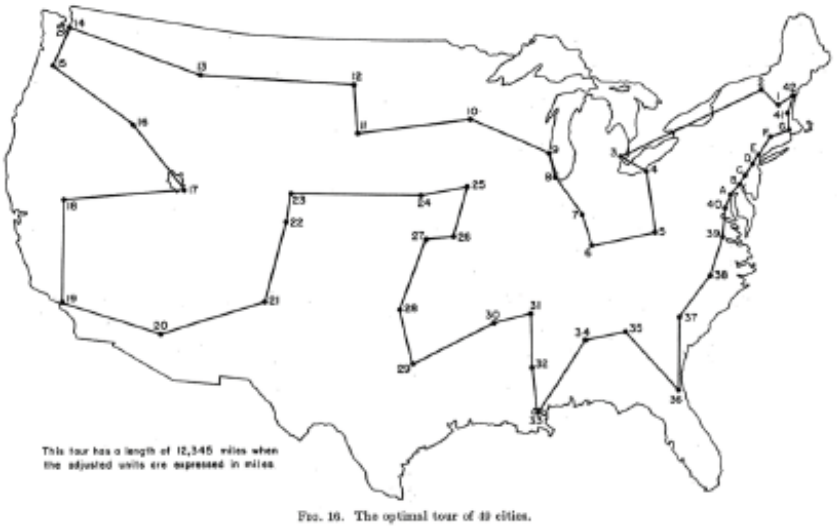
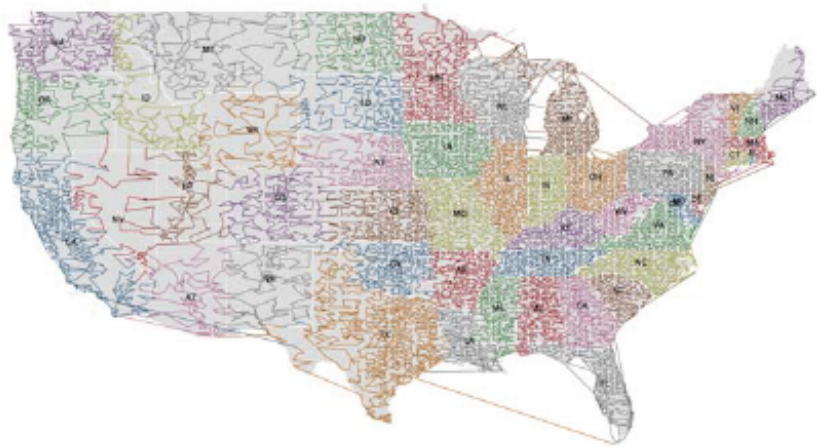


FIG. 16. The optimal tour of 49 cities.



In 1952, Dantzig et al. solve an instance of the Traveling Salesman Problem with 49 cities **by hand**

In 2006 Cook et al. solve a problem with 85,900 'cities' (the one above has 37,000 cities)

It took	It takes
> 4 months (early 90's)	1 second (2007)
> 7 years (early 90's)	1 second (now)

Parallel Computing

X1,000,000

X40

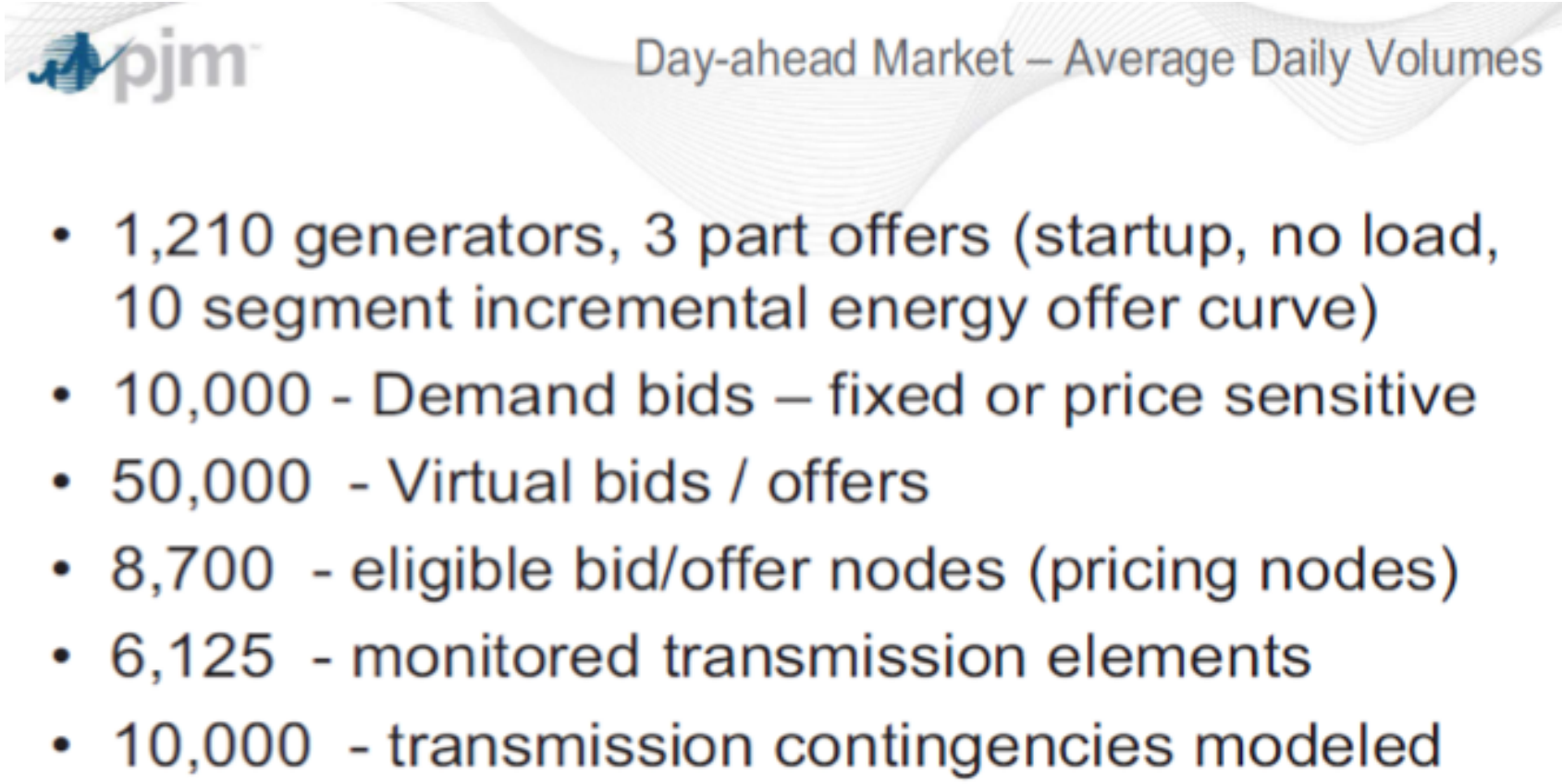
Intel Pentium II (1997-1999)	Intel Core i7 975 (2014)	Sequoia Cluster (2012)
233-450 MHz	3.33 GHz	PowerPC A2 2.3 GHz
1 core	4 cores	1.6 million cores

Operations Research in the Energy Industry

The energy industry is a *very active* user of OR

- Late 1980s: Lagrange relaxation applied in unit commitment
- Early 2000s: adoption of branch-and-bound in unit commitment, MISO reports $2.1 - $3 billion savings between 2007 and 2010!
- Late 1980s: stochastic dual dynamic programming solves medium-term hydrothermal scheduling, used in most hydrothermal systems today to determine water levels and prices (Brazil, Scandinavia, Turkey, Switzerland)

Example: PJM Day-Ahead Market Model



- Solved by mixed integer linear programming
- PJM traded \$50.03 billion (!) in 2014

Learning Outcomes

- Explain the architecture of electricity markets
- Formulate math programs that describe energy markets and regulations
- Formulate math programs that describe risk management
- Implement *models* using AMPL

Topics

- Mathematical background
- Power system operations
- Power market operations
- Economic dispatch, competitive market equilibrium
- The transmission network
- Ancillary services
- Unit commitment
- Financial instruments
- Demand response
- Capacity expansion