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From Smart Grids to Transcontinental Networks

The Future of Energy Systems

L. H. Tsoukalas

Outline

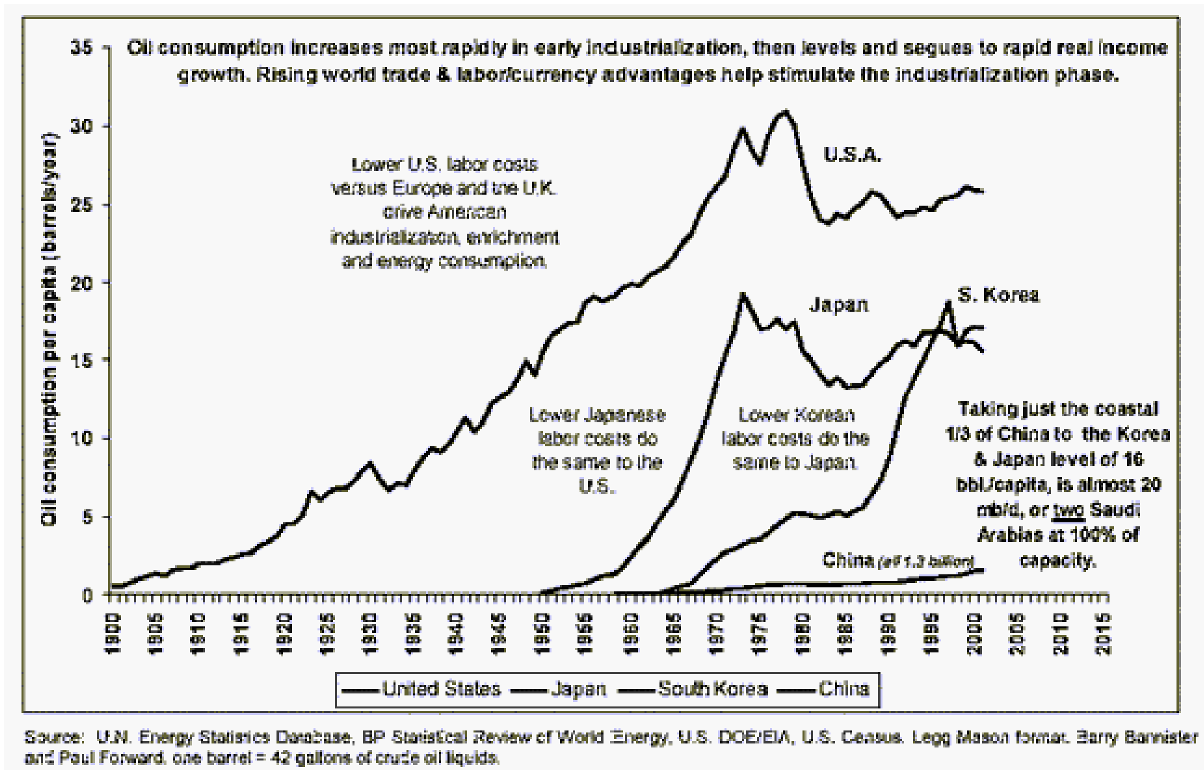
- Global Energy Realities
- Energy Economics 101
- Energy and ICT
- Conservation
- Smart Energy
- Energy Internet
- Examples
- Summary

Global Energy Realities

- World demand for energy exceeds 210 million barrels of oil equivalent (boe) per day

  (7.5 boe ~ 1 mtoe - metric ton of oil equivalent).
- World oil demand ~ 85 million barrels of oil per day (MM bpd)
- Aggregate world supply ~85+ million barrels of oil per day (MM bpd)
- International markets allocate resources by price
  - Need ~5% excess capacity for a stable market
  - Markets have difficulties directing capital towards infrastructural investments
  - Are we witnessing the beginning of a series of oil-induced market crises?

Oil Consumption Per Capita



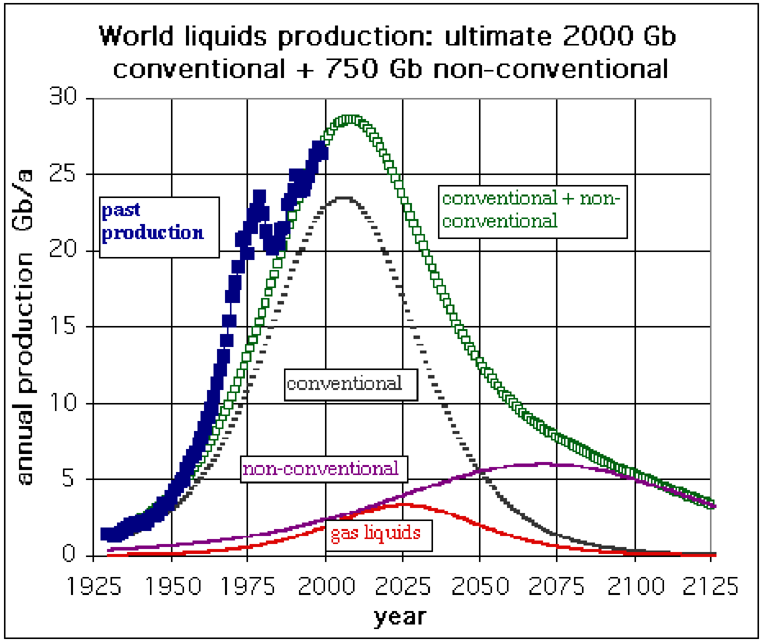
2010	**USA:**	**~25 barrels/year per capita**
	Europe/Japan/S. Korea:	**~15 barrels/year per capita**
	China:	**~2.0 barrels/year per capita**
	India:	**~1.0 barrels/year per capita**

Global Energy Growth

- Nearly seven billion people with modern desires
- Growth in energy demand has great margins for growth
  - 12% of the world uses 54% of all energy
  - 33% of the world still has no access to modern energy
  - The other 45% uses 1/4 of the energy consumed by remaining 12%
- Energy use by world's richest 12%
  - U.S.: 65 boe energy per person
  - Japan: 32 boe energy per person
  - U.K.: 30 boe energy per person
  - Germany: 32 boe energy per person

2005: Peak in Global Oil Production?

THE HUBBERT CURVE

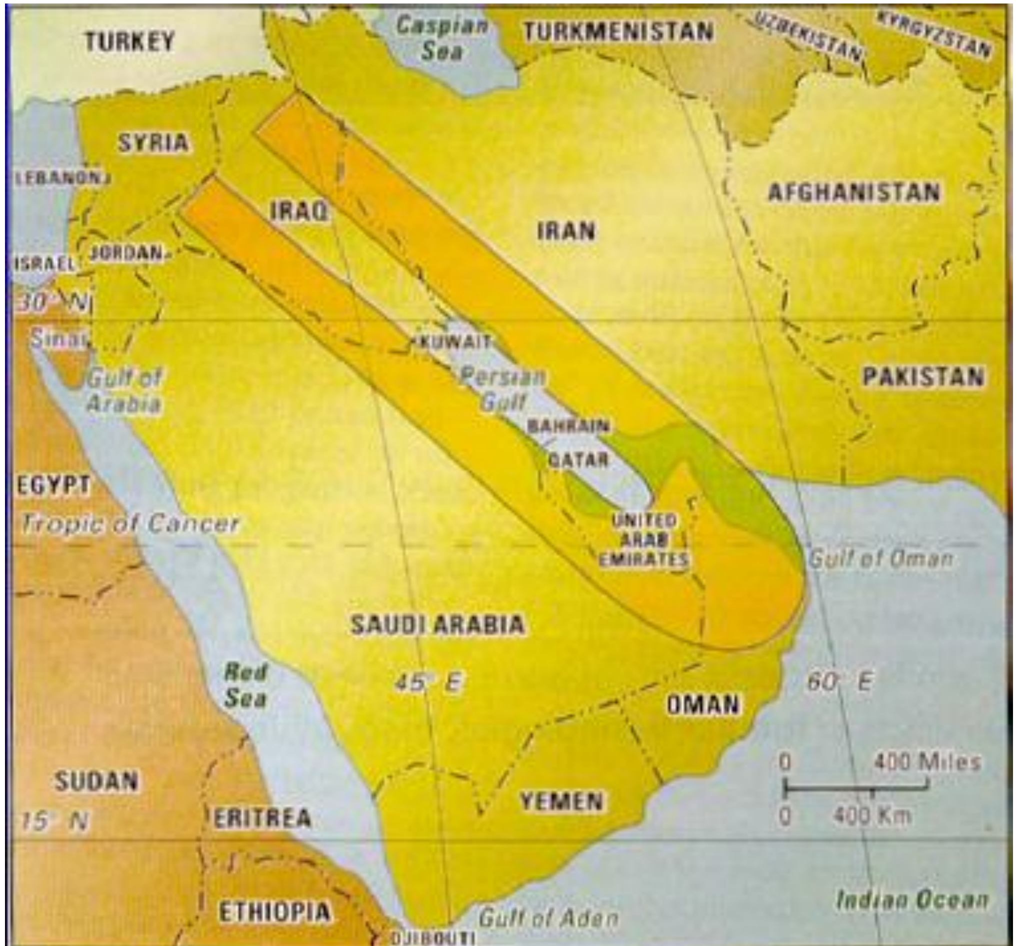


Peak by 2005-07: 85 mm bpd

By 2020: 50 mm bpd

Bakhtiari, S. A-M. *World Oil Production Capacity Model Suggests Output Peak by 2006-07* , Oil and Gas Journal (OGJ), May 2004

Conventional Oil: 70% of Remaining Reserves



Source: Dr. A.M. Samsam Bakhtiari, Senior Strategic Advisor, NIOC (2003).

Production at oil fields globally, including at the Kern River oil field in Bakersfield, California, is declining at about 4–6% a year.

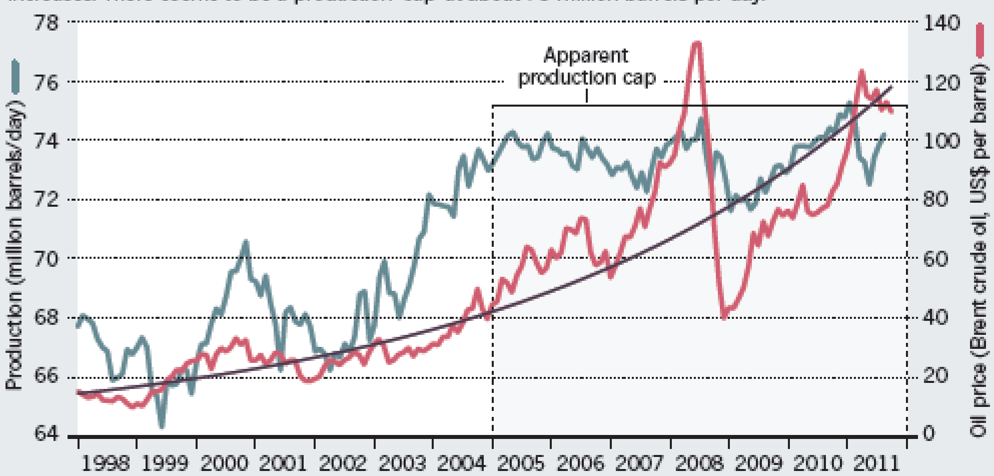
Oil's tipping point has passed

The economic pain of a flattening supply will trump the environment as a reason to curb the use of fossil fuels, say **James Murray** and **David King**.

Ref: King & Murray, Oil's Tipping Point has Passed, Nature, 2012

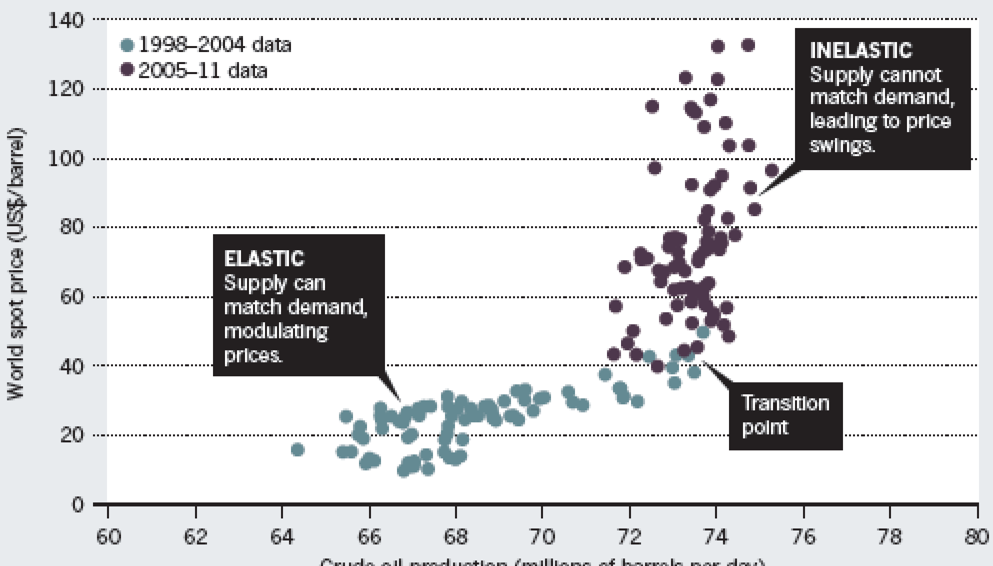
OIL PRODUCTION HITS A CEILING

Production followed demand until 2005, when it levelled off despite continued price increases. There seems to be a production 'cap' at about 75 million barrels per day.



PHASE SHIFT

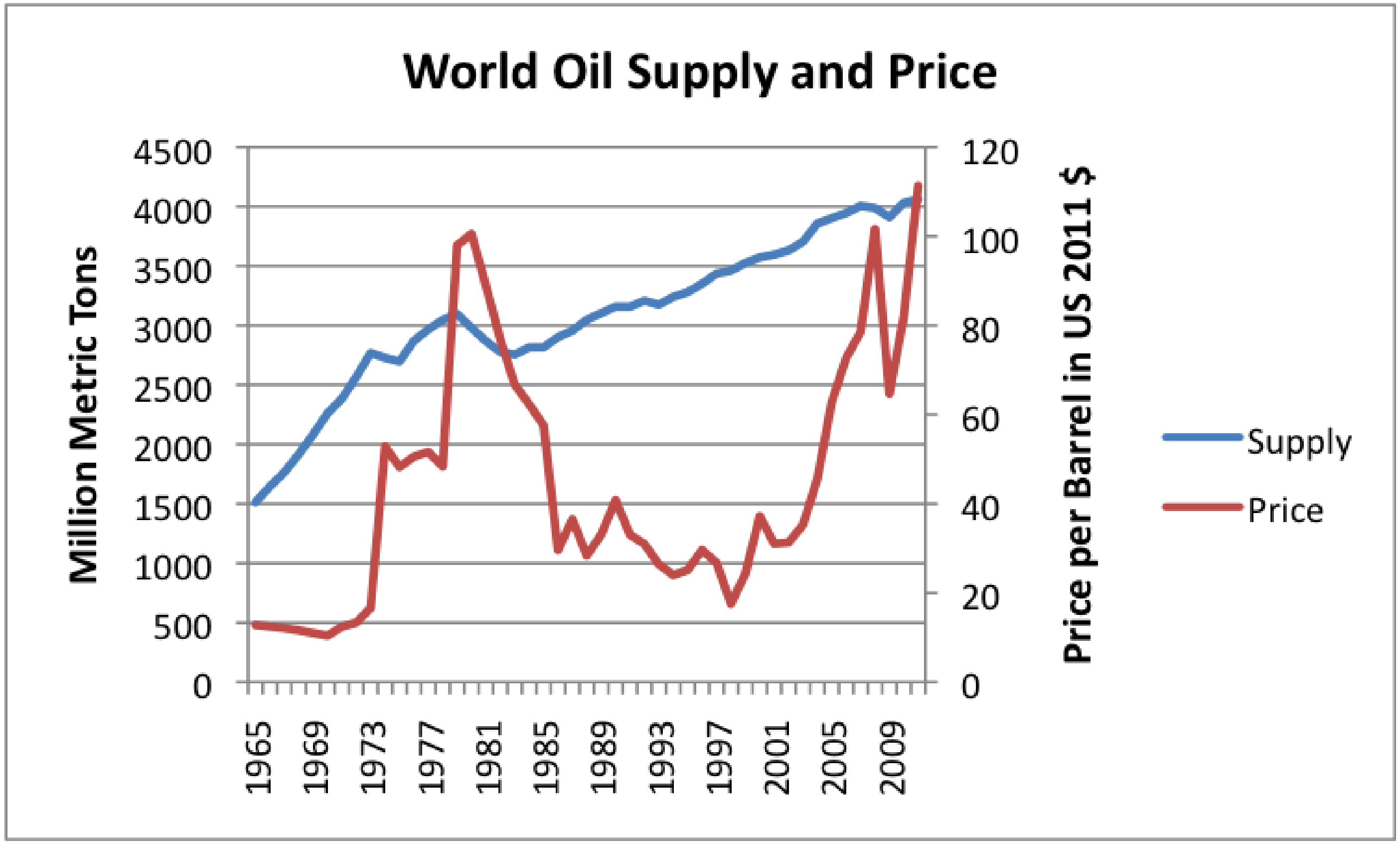
The abrupt change in oil economics can be seen in this scatter plot of production versus price.



The UK Industry Taskforce on Peak Oil and Energy Security and the UK government's Department of Energy and Climate Change are very aware of these risks, and have made a commitment to work together to protect the United Kingdom and its economy from rising oil prices. The task force, formed in 2008, warned that Britain must not be caught out by the oil crunch, and said that policies to address 'peak oil'

> ***"The price of oil is likely to have been a large contributor to the euro crisis in southern Europe."***

Oil supply and price



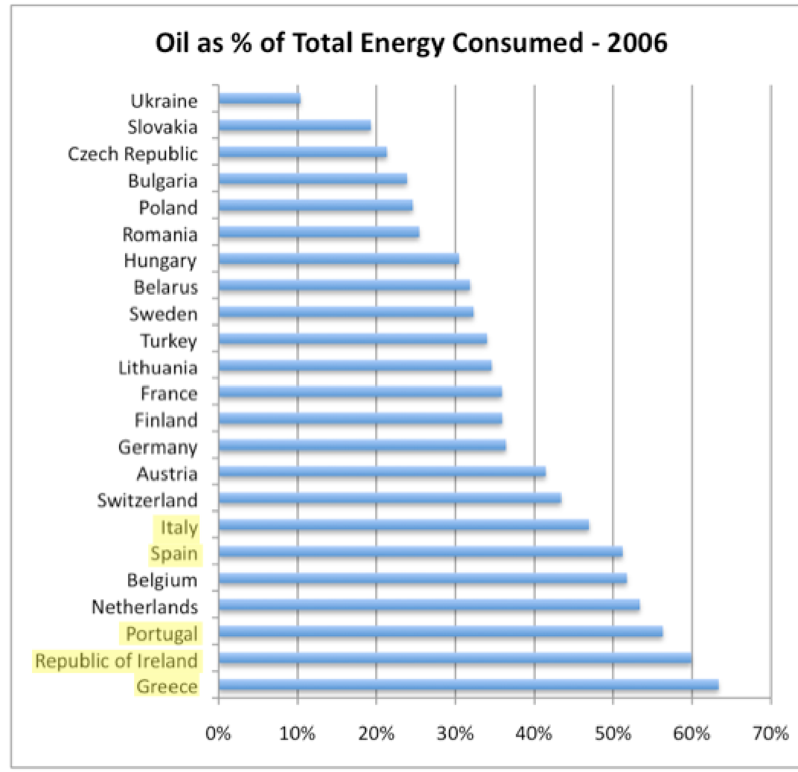
2011 Libya War: Reduced global oil supply by 1.7% → oil prices rose 17%

Based on data from BP's 2012 Statistical Review of World Energy.

Source: G. Tverberg, 2012

Declining Oil Consumption → Recession

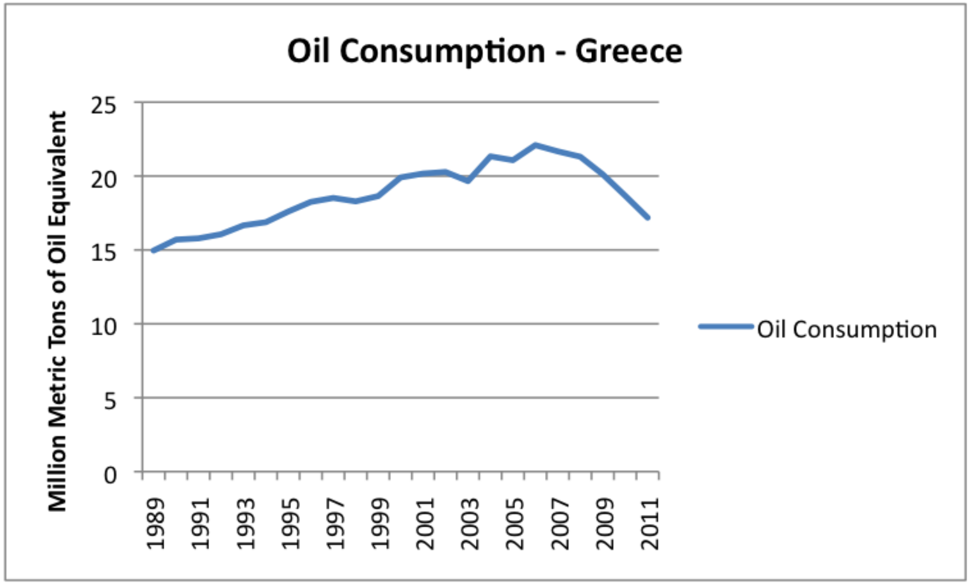
- Greater risk
  - Oil importing countries
  - High oil consumption/ total energy
  - Can't regulate own currency
  - Debt from previous high growth
- Lower risk countries also affected



Source: G. Tverberg, 2012

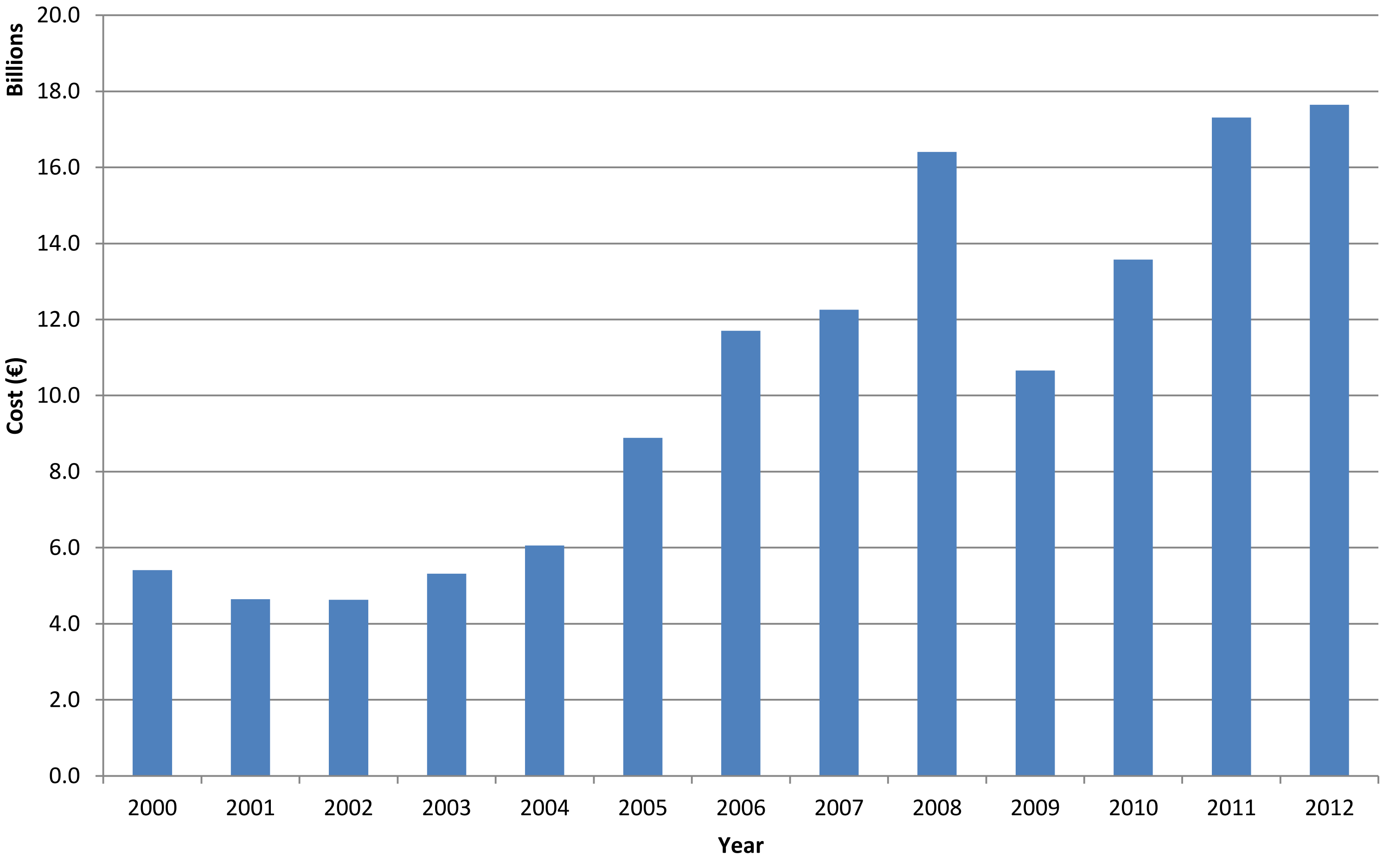
Energy-Recession Example: Greece

- Tourism biggest industry – oil dependent
- Lots of previous debt-based growth
- Now: Rising unemployment; multinational companies leaving; taxes not sufficient to pay for entitlements



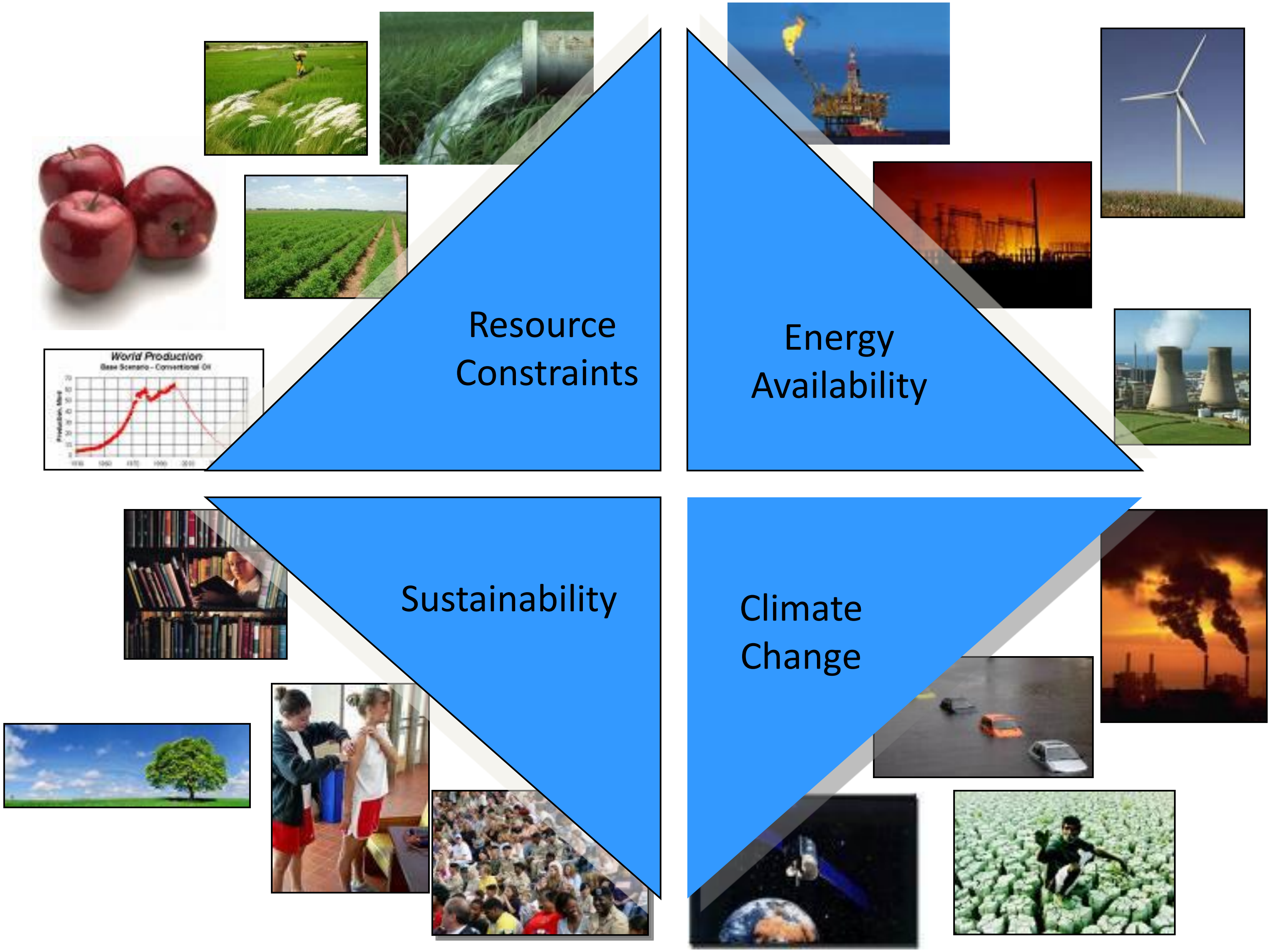
Source: G. Tverberg, 2012

Oil Imports Expenditures



Source: Bank of Greece

Utopia *vs* Dystopia



Energy and ICT

Energy is involved in a vast technology-based transformation

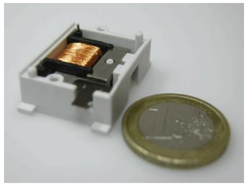
Software services and machine intelligence lead the transformation.

The process of ***collecting, modeling, interpreting***, and ***implementing*** hydrocarbon delivery involves time delays from the original market "signal" to market response.

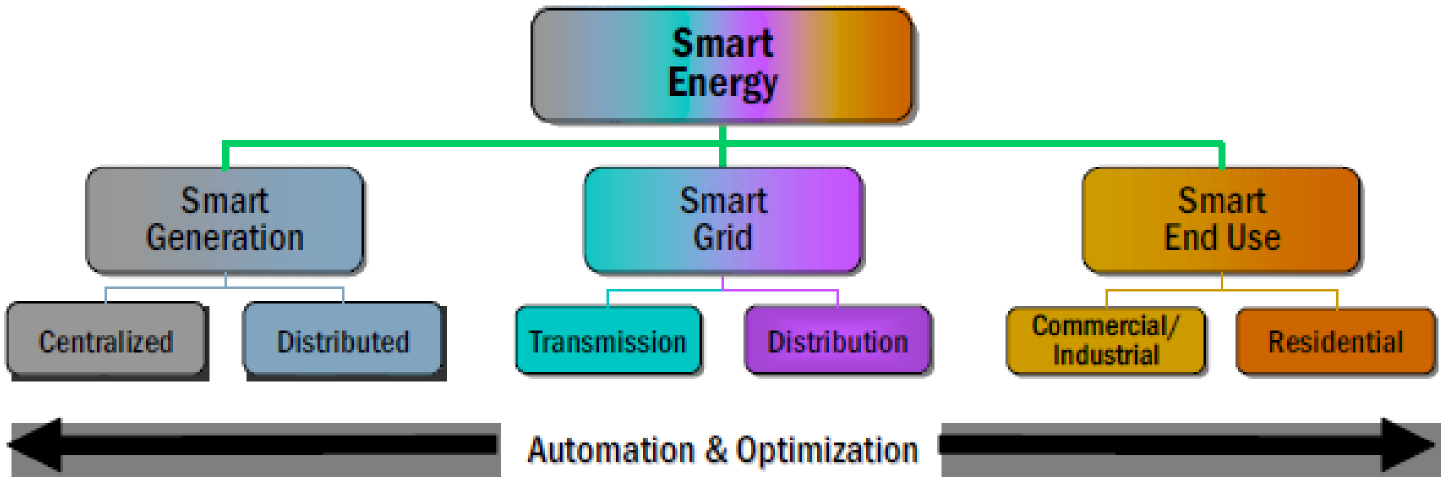
On the other hand electricity delivery is instantaneous, easier, faster, but also less efficient.

Doing More with Less

- ***Conservation*** may be our greatest new energy discovery in the near future
- Smart energy can facilitate further convergence of IT, power, and, transportation infrastructures
- Smart energy can facilitate integrated utilization of new energy carriers
  - H_2, Alcohols, Biofuels
- Can harvest energy usually wasted
- Ambient energy MEMS


Energy + Intelligent Systems

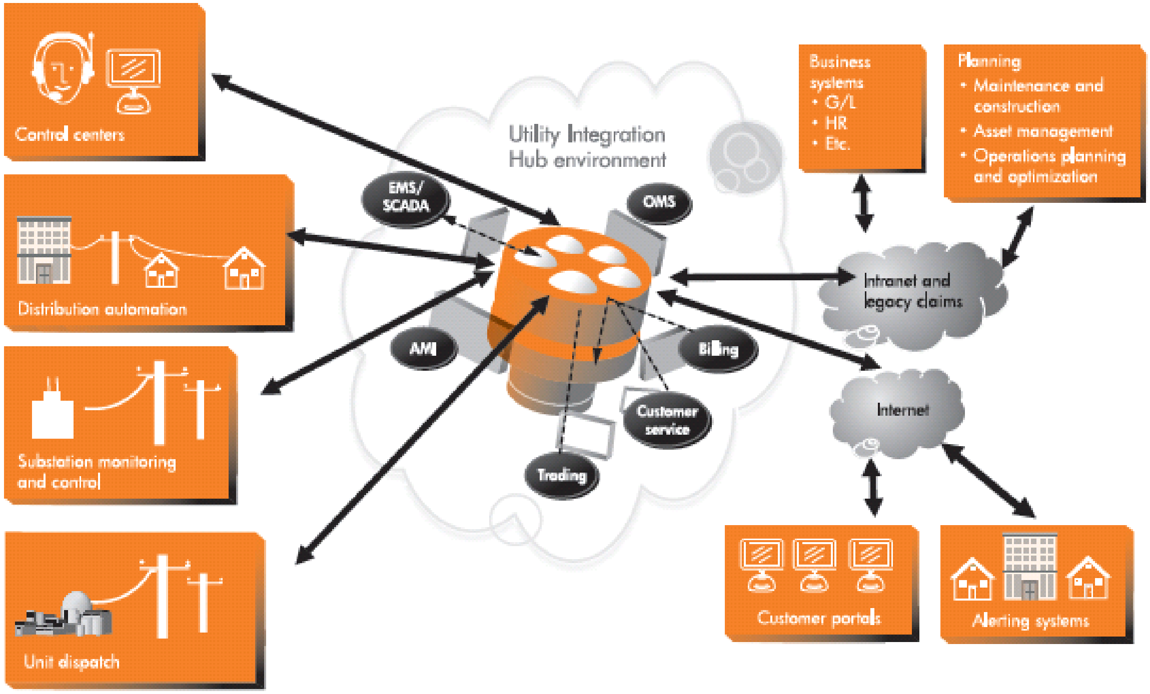


- Smart Energy = Energy + Intelligent Systems
- Smart energy extends throughout the electricity value chain
  - Smart Generation
  - Smart Grid
  - Smart Loads (End Use)

Current Smart Energy Distribution Management Systems

- Advanced Metering Infrastructure
- Supervisory Contro and Data Acquisition (SCADA
- Capacitor Bank Control

Singapore:
Smart Energy Vending



HP's Utility Integration Hub for real-time service integration

Source: HP's, *Smart Energy Distribution Management Systems*, 2005

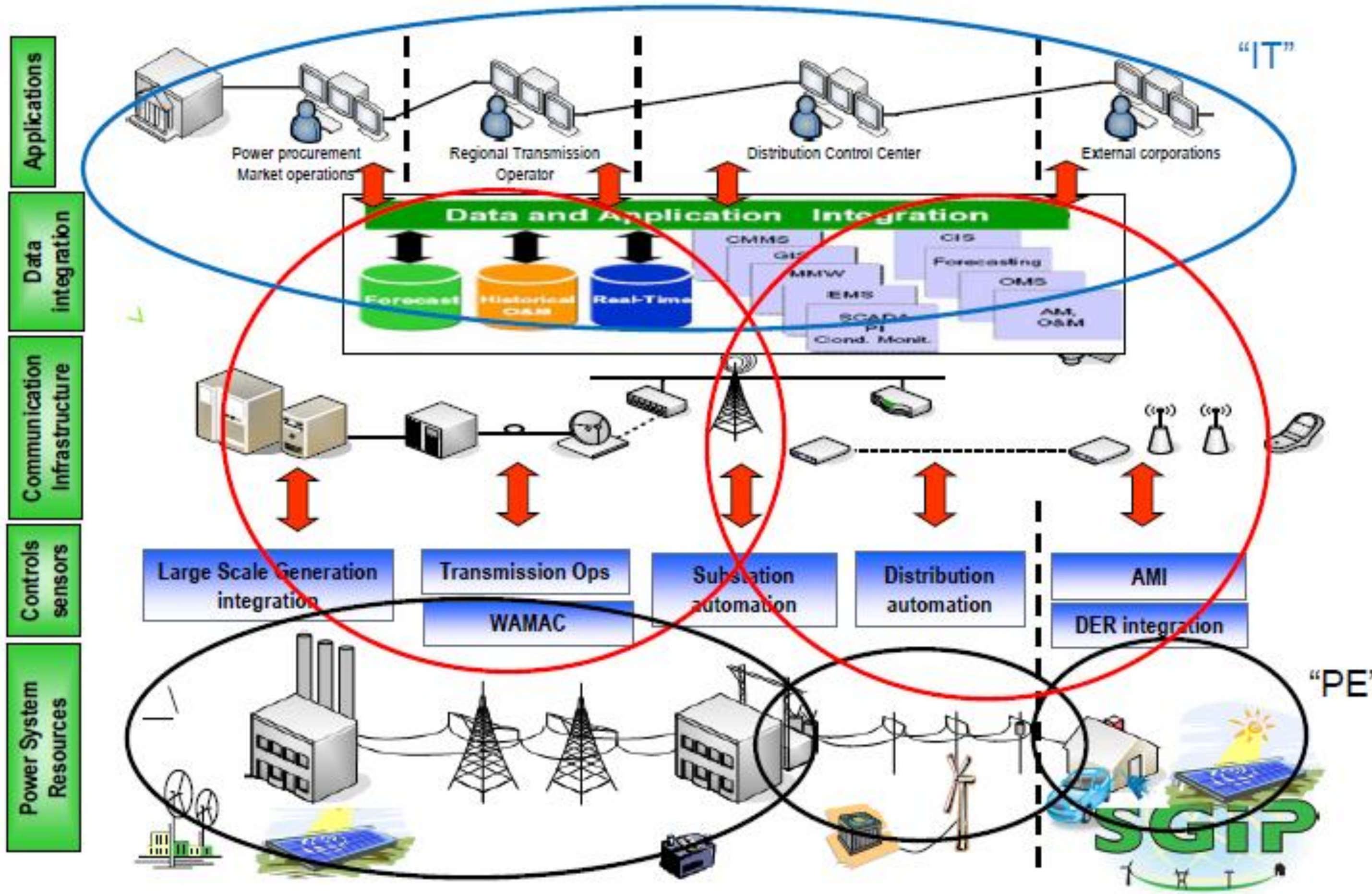
Power Grid

- Secure and reliable energy delivery becomes a pressing challenge
  - Increasing demands with higher quality of service
  - Declining resources
- The North American electric power grid is operating under narrower safety margins
  - More potential for blackouts/brownouts
  - Efficient and effective management strategy needed
- Current energy delivery infrastructure is a super complex system (more *evolved* than *designed*)
  - Lack of accurate and manageable models
  - Unpredictable and unstable dynamics
- Can we build an inherently stable energy network for future generations?

Smart Grid

- Smart grids is an advanced concept
  - Detect and correct incipient problems at their very early stage
  - Receive and respond broader range of information
  - Possess rapid recovery capability
  - Adapt to changes and reconfiguring accordingly
  - Build in reliability and security from design
  - Provide operators advanced visualization aids
- Most of these features can be found in the Information Internet
  - The Internet is also a super complex system
  - It is remarkably stable
- Can we find an Internet type of network for energy systems?

Smart Grid Architecture



Source: Hughes, J., Smart Grid Architecture Development, IEEE S.F., Oct. 17, 2011

Future Grid with Increasing Complexity

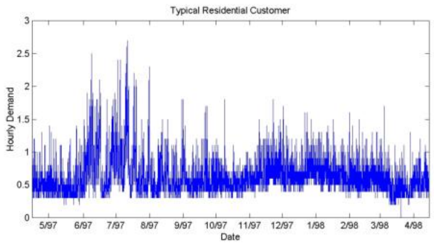
- Existing sources:
  - Transmission/distribution network.
  - Consumption (demand-side stochasticity).
  - Regulation.
- Emerging sources:
  - Renewables (supply-side stochasticity).
  - Electric vehicles (double-stochasticity).
  - Environmental factors.

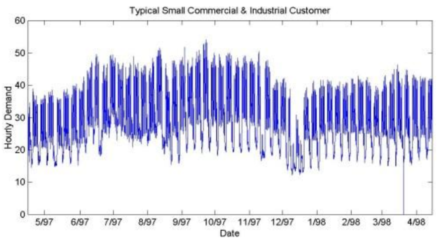
Managing Complexity

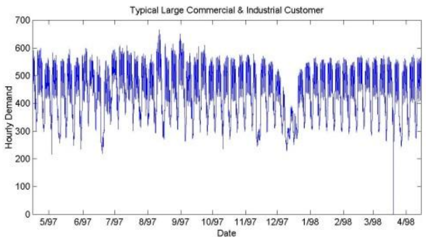
- Reducing stochasticity
  - Aggregation of small residential customers.
  - Load forecasting.
- Regulating interactions
  - Smart meters.
  - Pricing via short term elasticity.
- Integrated market design

Unpredictability on Demand Side

Typical Hourly Consumption of:







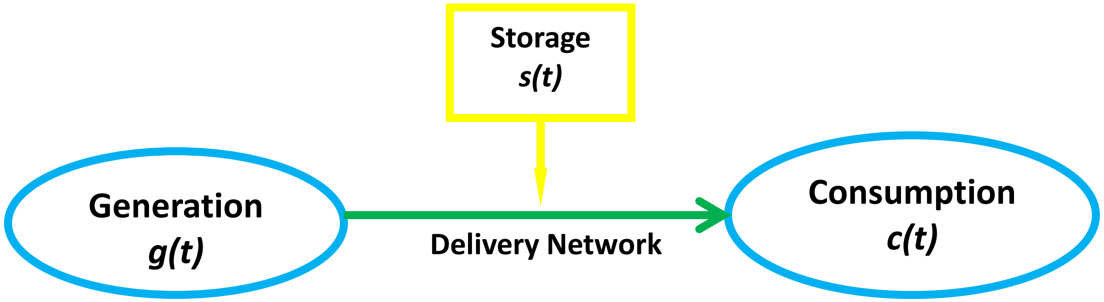
Residential Customer

Small Business

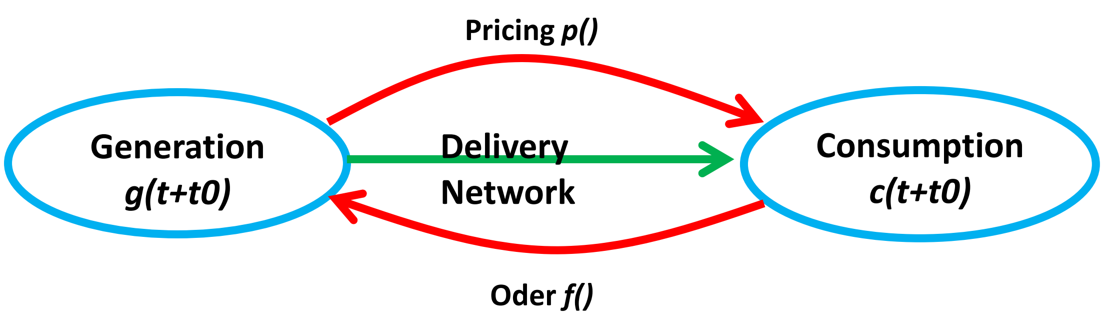
Large Industry

Managing Complexity: Regulating Interaction

Option 1: Open-Loop System with Sufficient Storage



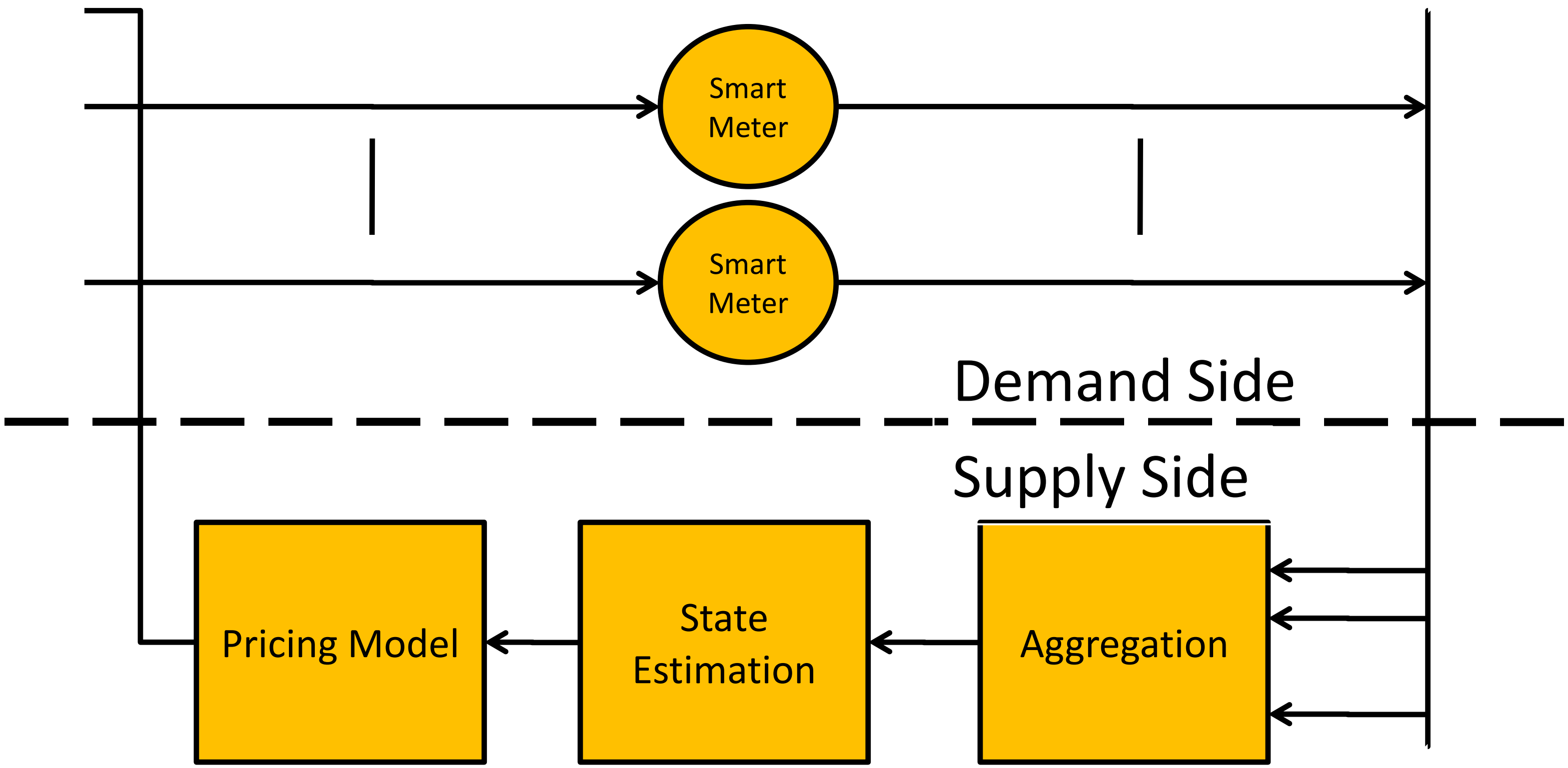
Option 2: Closed-Loop w/ Anticipation and Pricing Signals



Equilibrium is reached at **future** state!

Integrated Market Design

With smart meters and price elasticity models

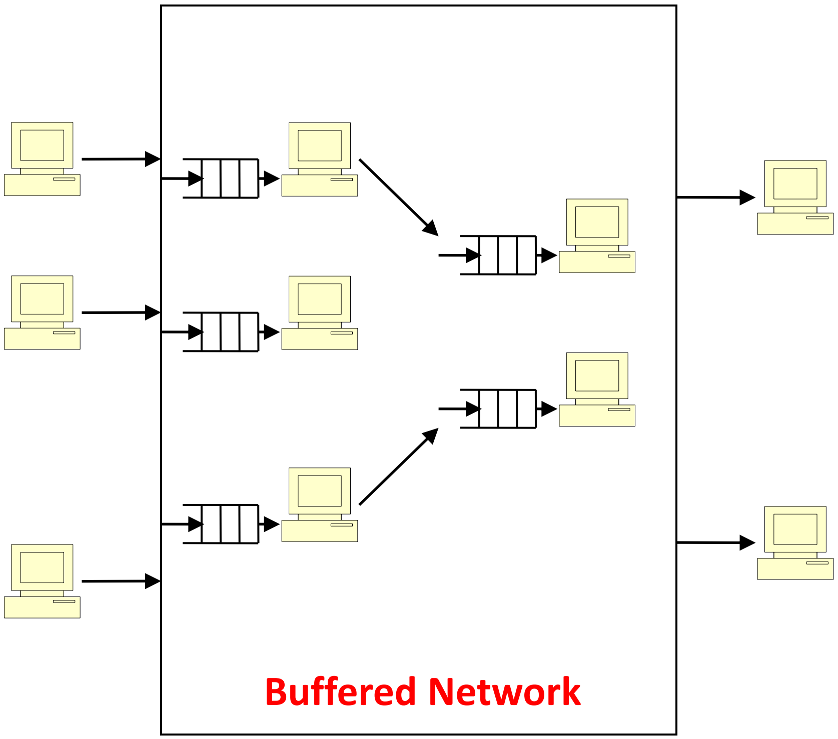


An Energy Internet

- Benefits of an Energy Internet
  - Reliability
    - Self configuration and self healing
  - Flexibility and efficiency
    - Customers can choose the service package that fits their budget and preferences
    - Service providers can create more profits through real-time interactions with customers
    - Marketers or brokers can collect more information to plan more user-oriented marketing strategies
    - The regulation agency can operate to its maximal capacity by focusing effectively on regulating issues
  - Transparency
    - All energy users are stakeholders in the Energy Internet

Storage and Buffer

- Internet adopts a set of protocols to resolve conflicts caused by the competitions over limited resources (bandwidth)
- What make these protocols feasible is the assumption that information transmitted over the network can be **stored and retransmitted**.



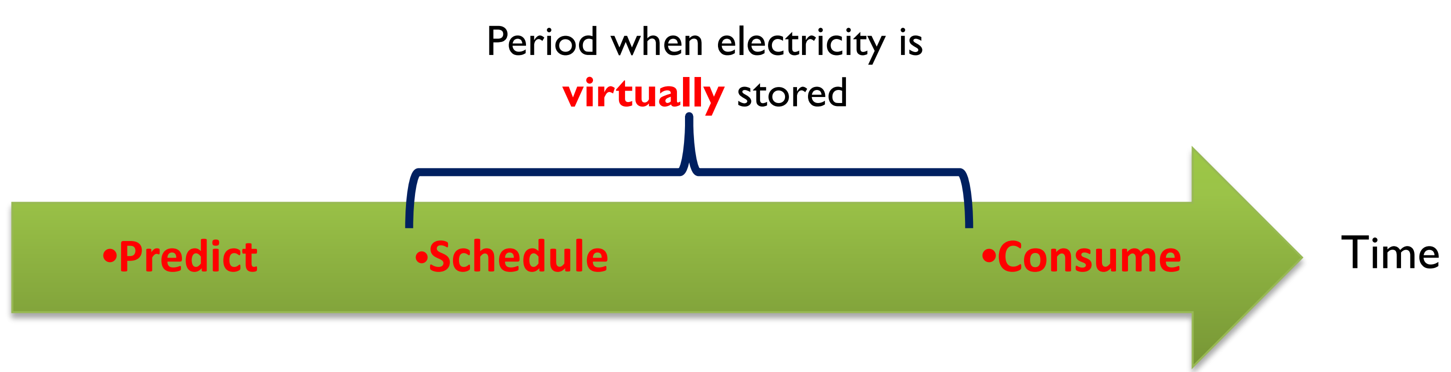
Energy Storage

- Similar protocols could be developed for the power grid in order to
  - Resolve conflicts due to the competitions over resources and
  - Identify and contain problems locally

  IF electricity can be stored in the grid(!)
- Unfortunately, large scale storage of electricity is technologically and economically not feasible
- Solution: a virtual buffer
  - Electricity can be virtually stored if enough information is gathered and utilized

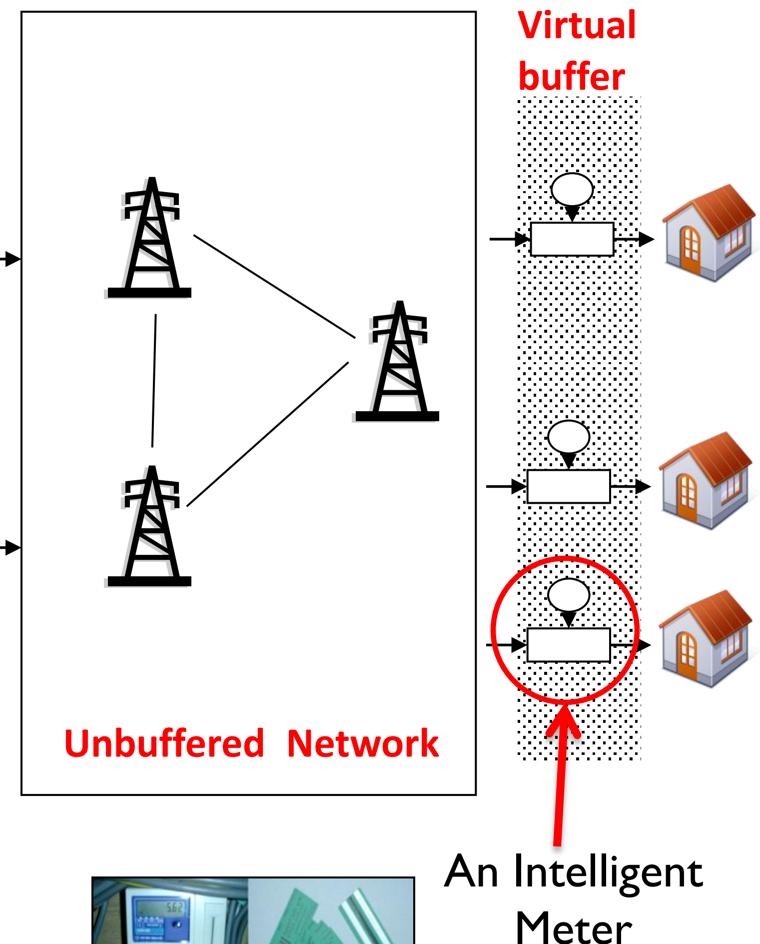
Virtual Buffer: Concepts

- Assume predictability of demand
- Based on demand forecast, the desired amount of electricity is ordered (by an intelligent agent on behalf of the customer) ahead of time
- The supplier receives orders and accepts them only if all constraints are met. Otherwise, new (higher) price may be issued to discourage customers (devices) from consuming too much electricity
- Price elasticity is used by the supplier to determine the amount of adjustment on price
- Once the order is accepted, from a customer's point of view, electricity has been virtually generated and stored



Virtual Buffer: Implementation

- Information can be used to achieve the virtual storage of energy
- Two keys for implementation
  - know electricity demand for individual customers in advance
  - Regulate demand dynamically
- Hardware
  - An intelligent meter for every customer to handle the planning and ordering automatically
- Algorithms
  - Demand forecast
  - Dynamical regulation via price elasticity



Long- and Short-term Elasticity

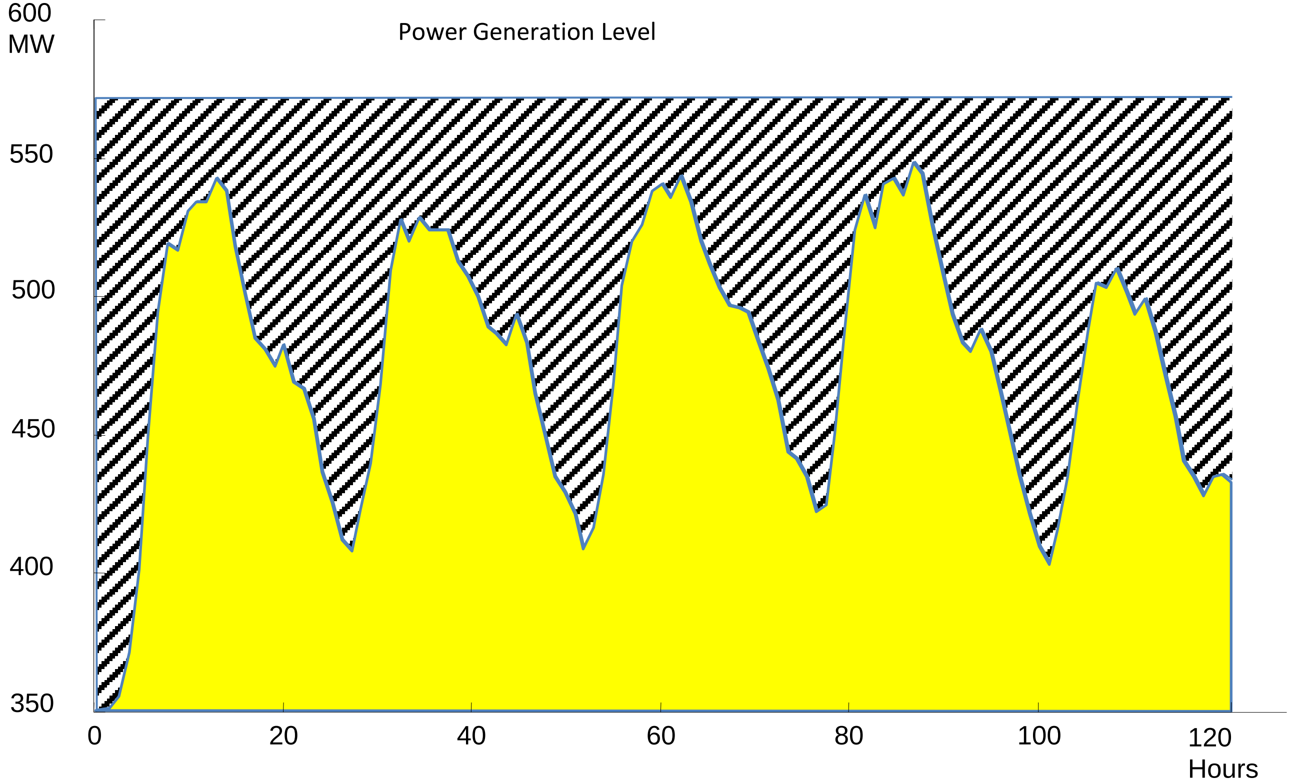
- Long-term Elasticity
  - Average elasticity in within a long period (moths, years)
  - Usually is an overall index including a large number of customers
  - Good for long-term strategic planning
  - More reliable to estimate
- Short-term Elasticity
  - Instant elasticity within a very short period (e.g., minutes, hours)
  - Can be a local index for a particular customer
  - Critical for control of the power flow
  - Difficult to estimate

Managing Short-term Elasticity

- Short-term price elasticity characterizes a particular customer's nearly instantaneous responsiveness to the change of price
- Short-term elasticity can be estimated from
  - Historical price-demand data
  - Psychological models of customer *energy behaviors*
- The use of intelligent meters is important for
  - Increasing short-term elasticity => more effective for control
  - Regulating customers' behavior => more reliable for prediction

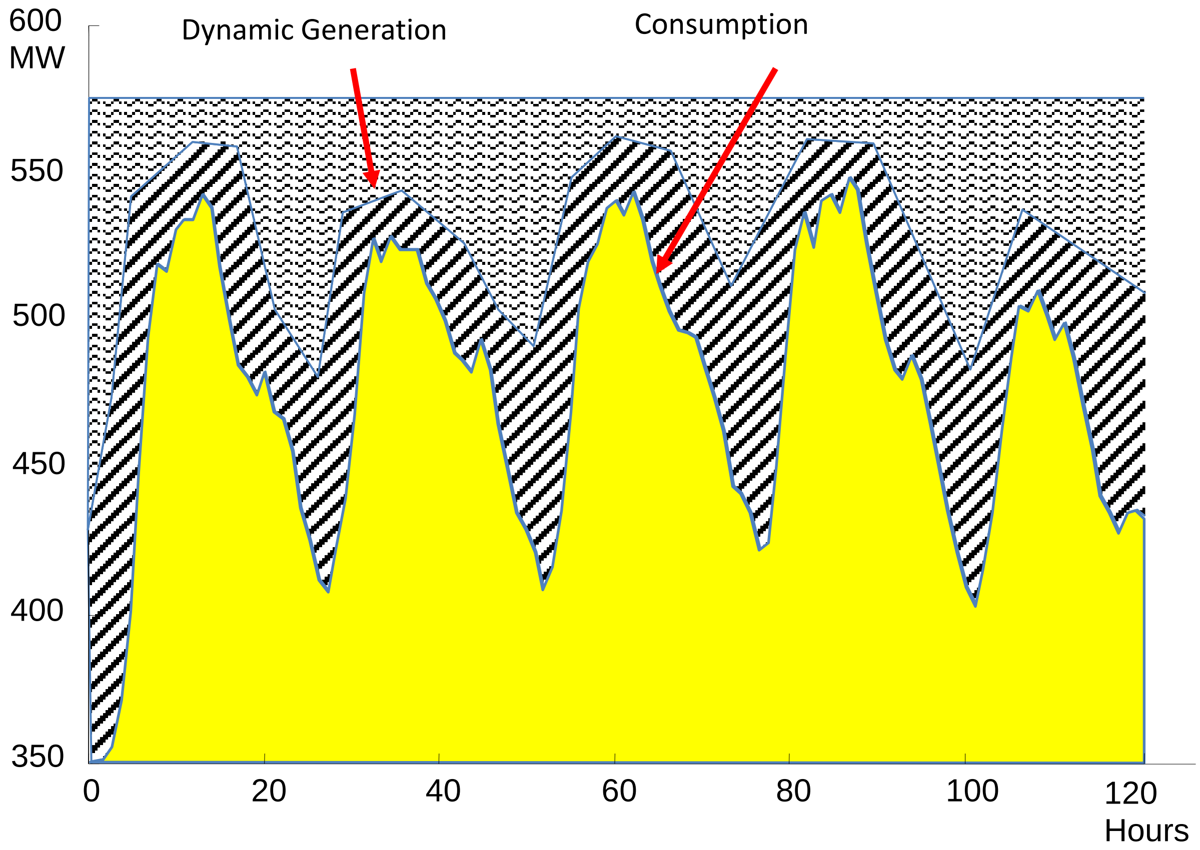
Saving is Conserving (I)

- Without anticipation, energy waste is enormous



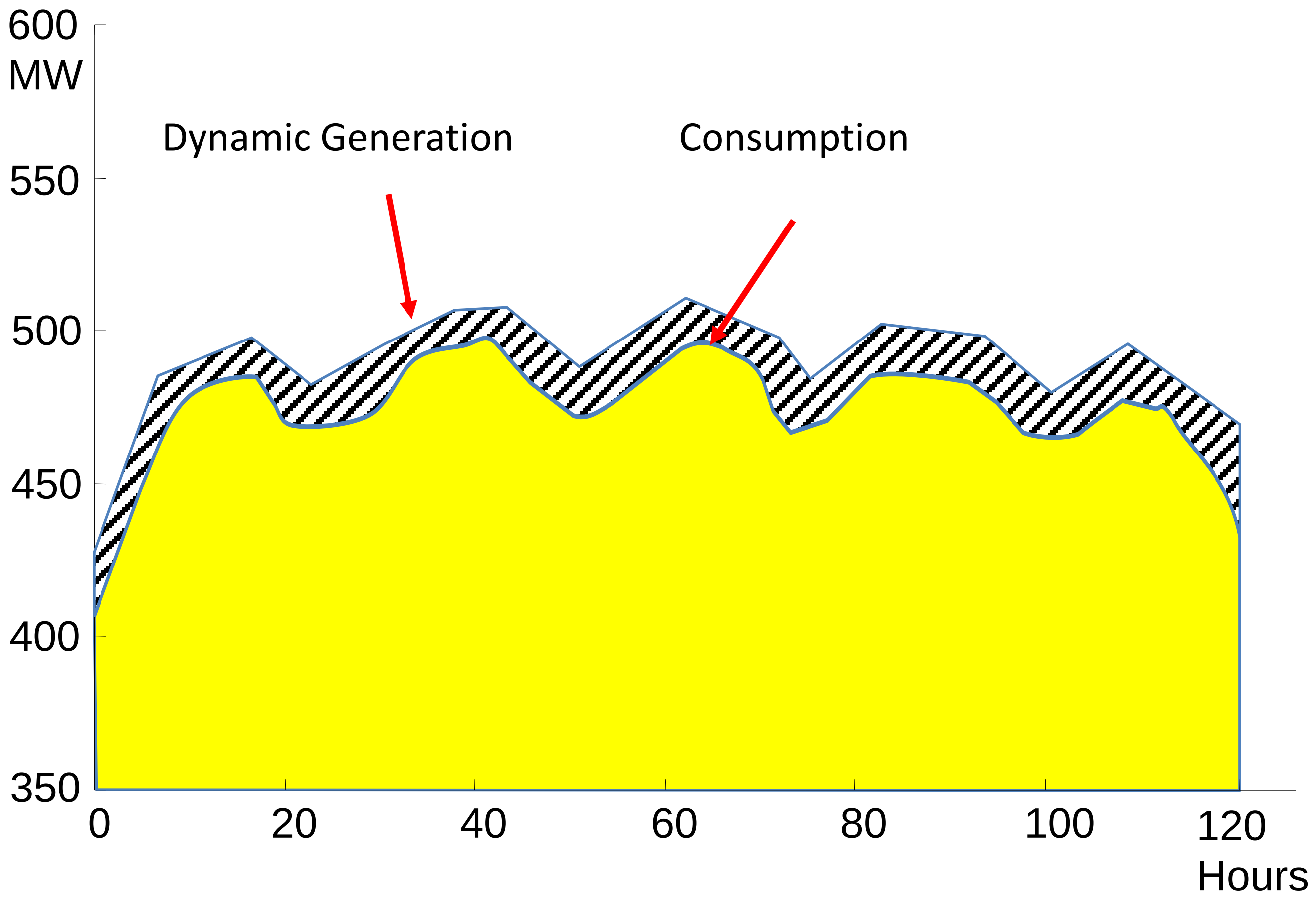
Saving is Conserving (II)

- With anticipation, energy waste can be dramatically reduced

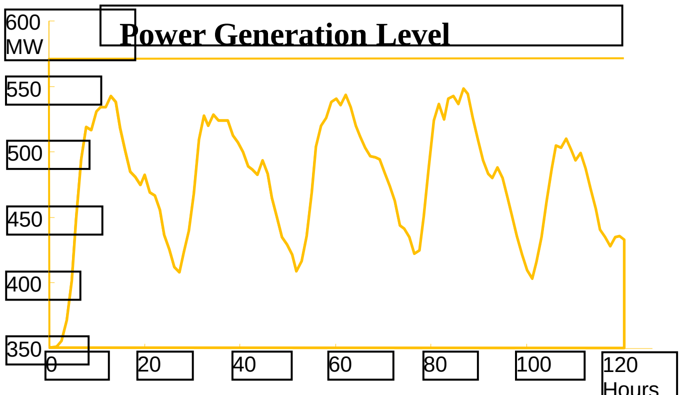


Saving is Conserving (III)

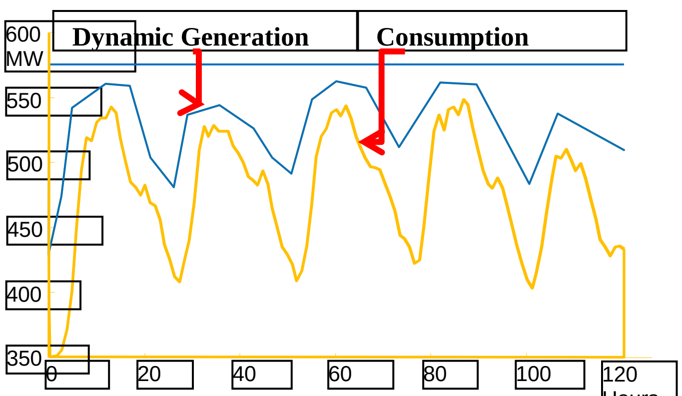
- Anticipation and price elasticities result in energy saving and elevated stability



Load Shaping with Pricing Signals

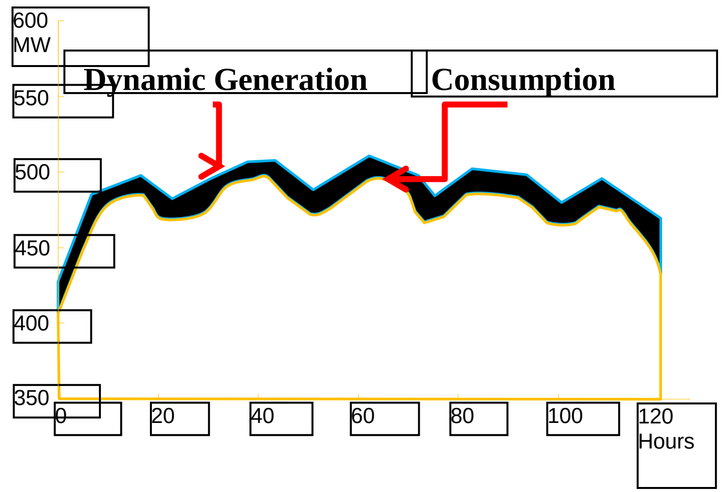


Without anticipation



With anticipation

Smaller margins required

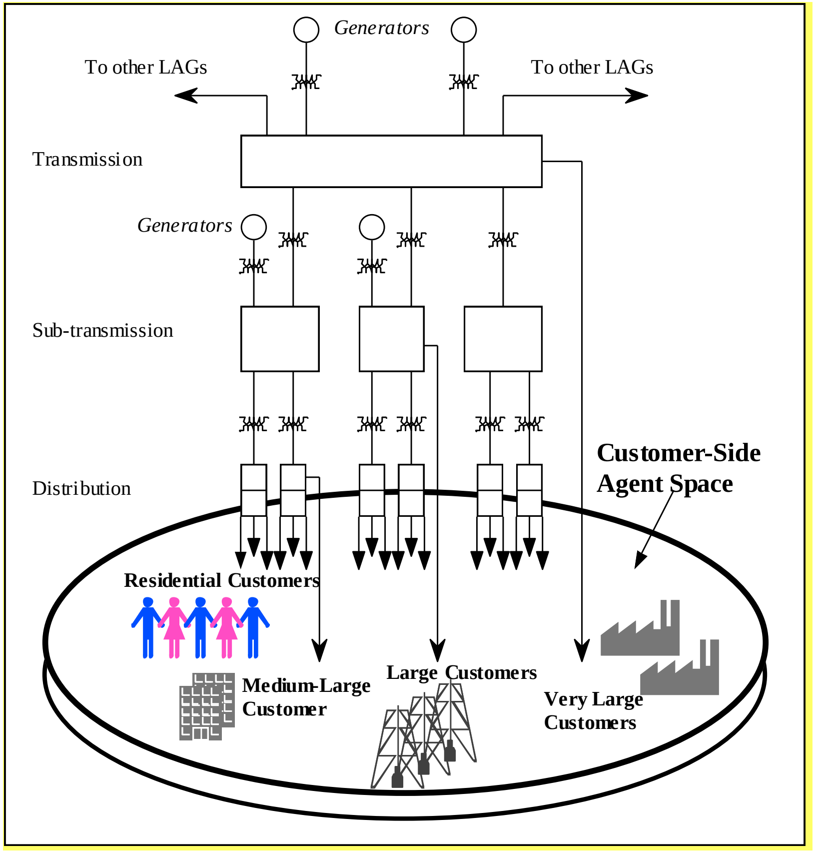


With anticipation and pricing

Load shaping enable highest efficiency

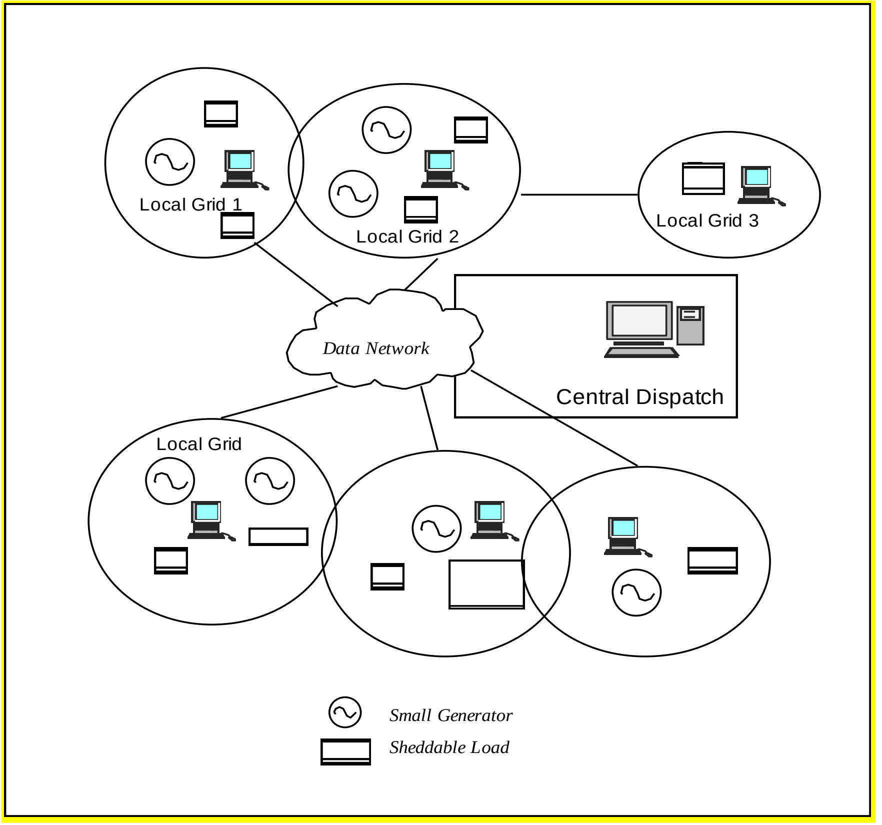
Example Approach

- Grid is viewed as polycentric and multilayered system
- Customer-driven
- Grid segmented by groups of customers (LAGs)
- Accurate predictions of nodal demand drive the system
- Optimal dispatch of units (storage)
- *Plug and play* tool: TELOS

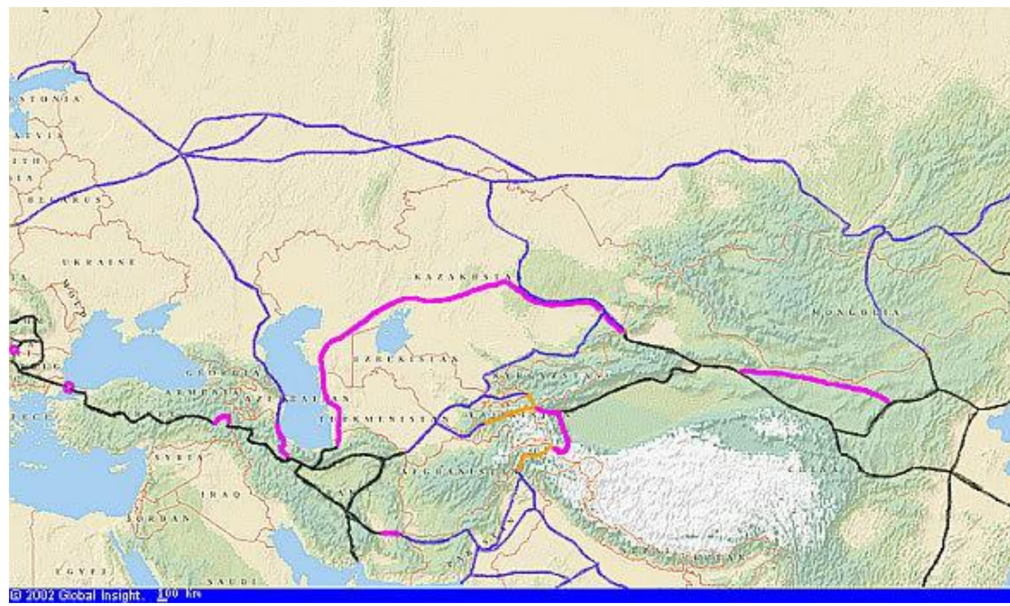


Local Area Grid - LAG

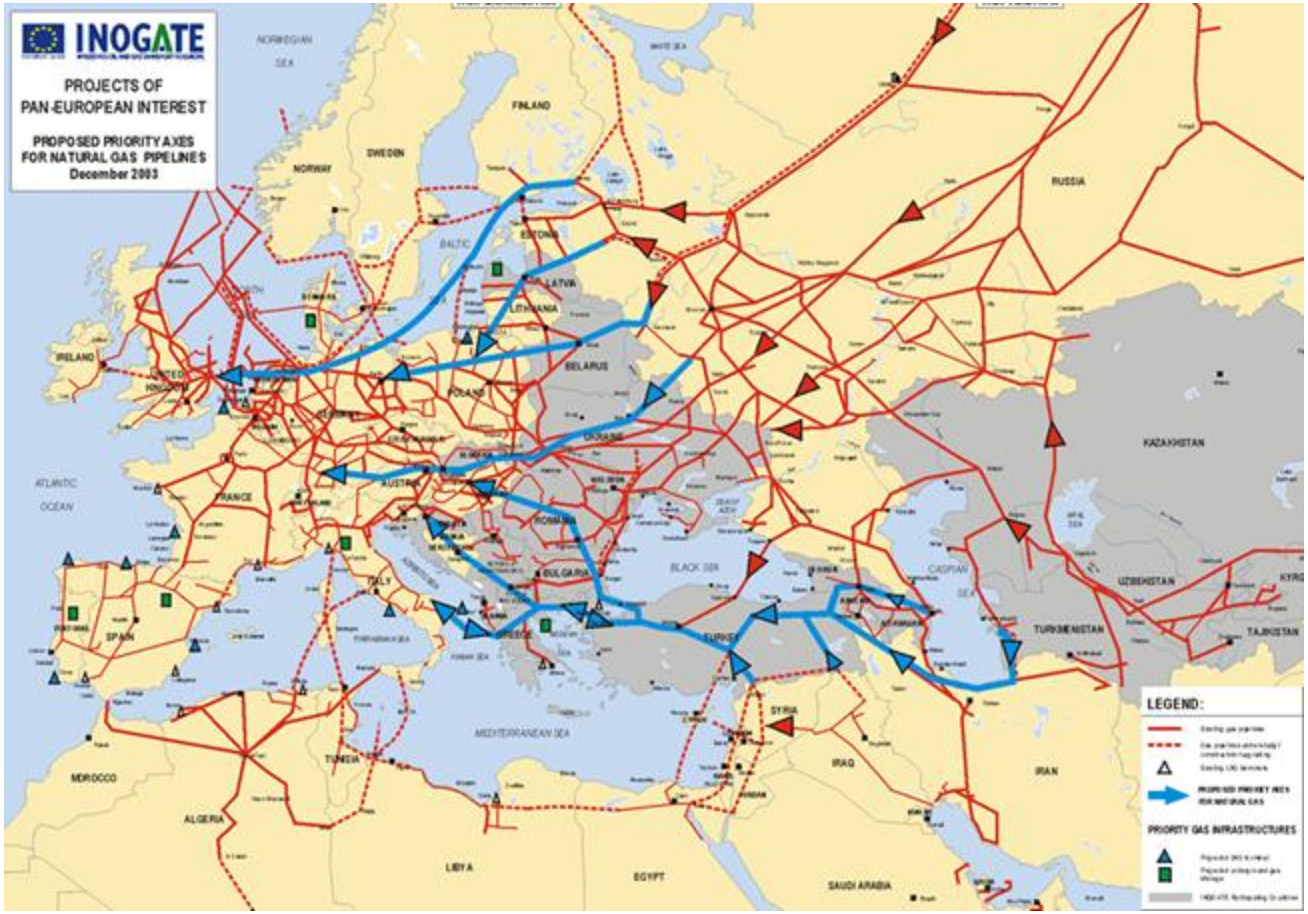
- Defined as a set of power customers
- Power system divided into *Local Area Grids* each with anticipatory strategies for
  - Demand-side management
  - Dispatching small units
  - Energy storage
  - Good neighborly relations



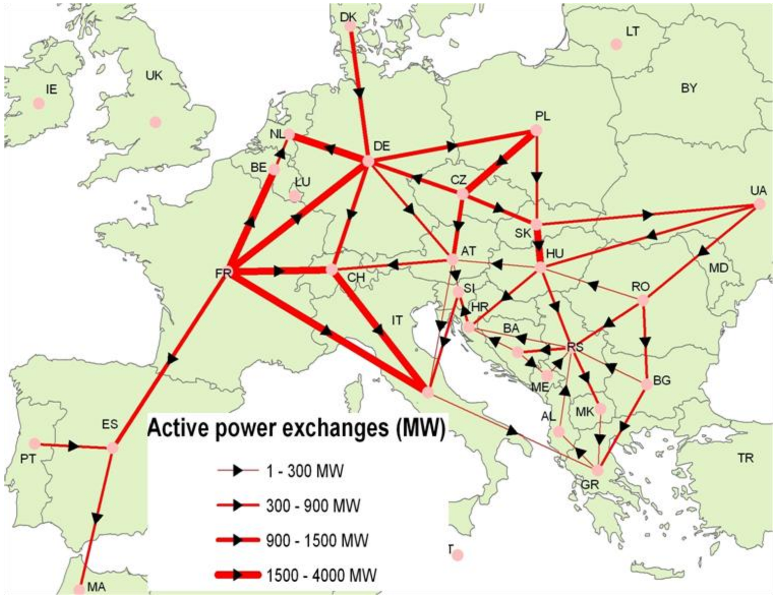
Transcontinental Energy Networks



Europe Middle East North Africa (EUMENA) NG Flows



Europe and future EUMENA Power Flows



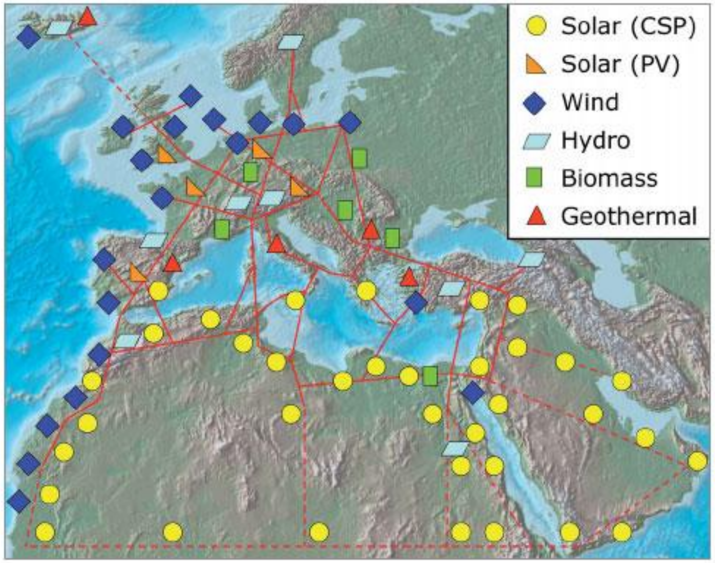
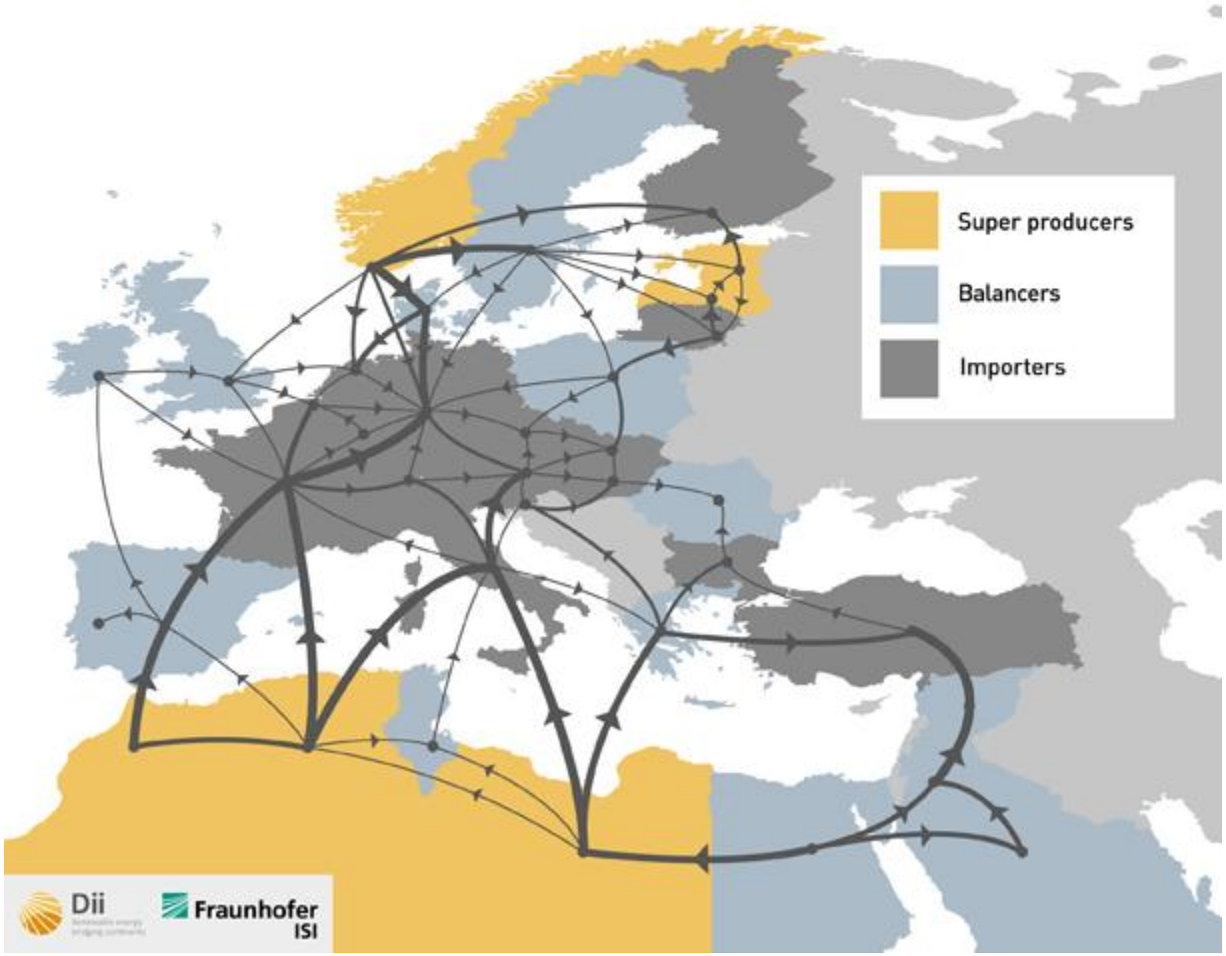


Figure 9: Concept of a EUMENA interconnected electricity grid based on HVDC power transmission as "Electricity Highways" to complement the conventional AC electricity grid. TREC 2006.

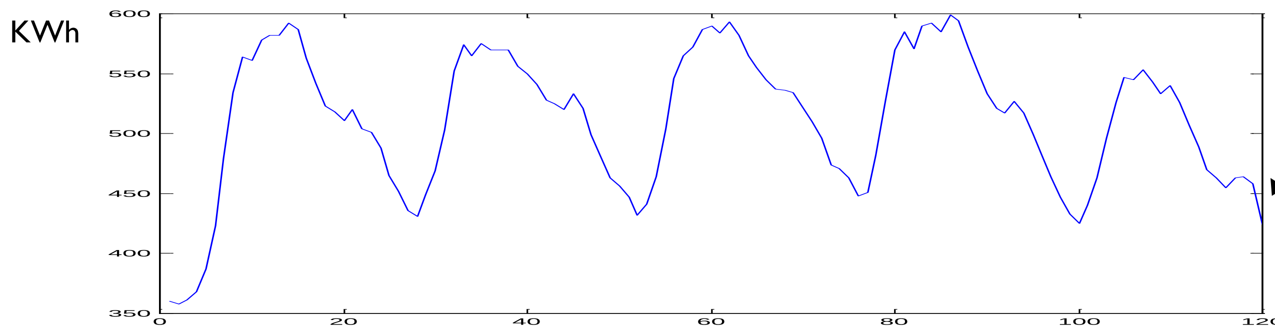
NORTH & SOUTH – EUMENA'S POWERHOUSES 2050



TELOS Design Requirements

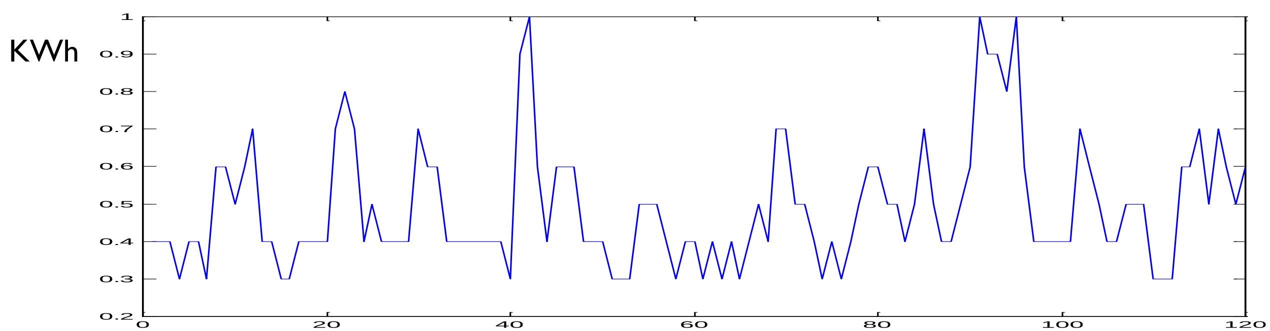
- **TELOS =** **T**ransmission-distribution **E**ntities with **L**earning and **O**n-line **S**elf-healing
- Local Area Grid (LAG)
- Customer-centric
- System Model
- Power System Calculations
- User Interface
- Automated Execution

Examples of Customers in TELOS



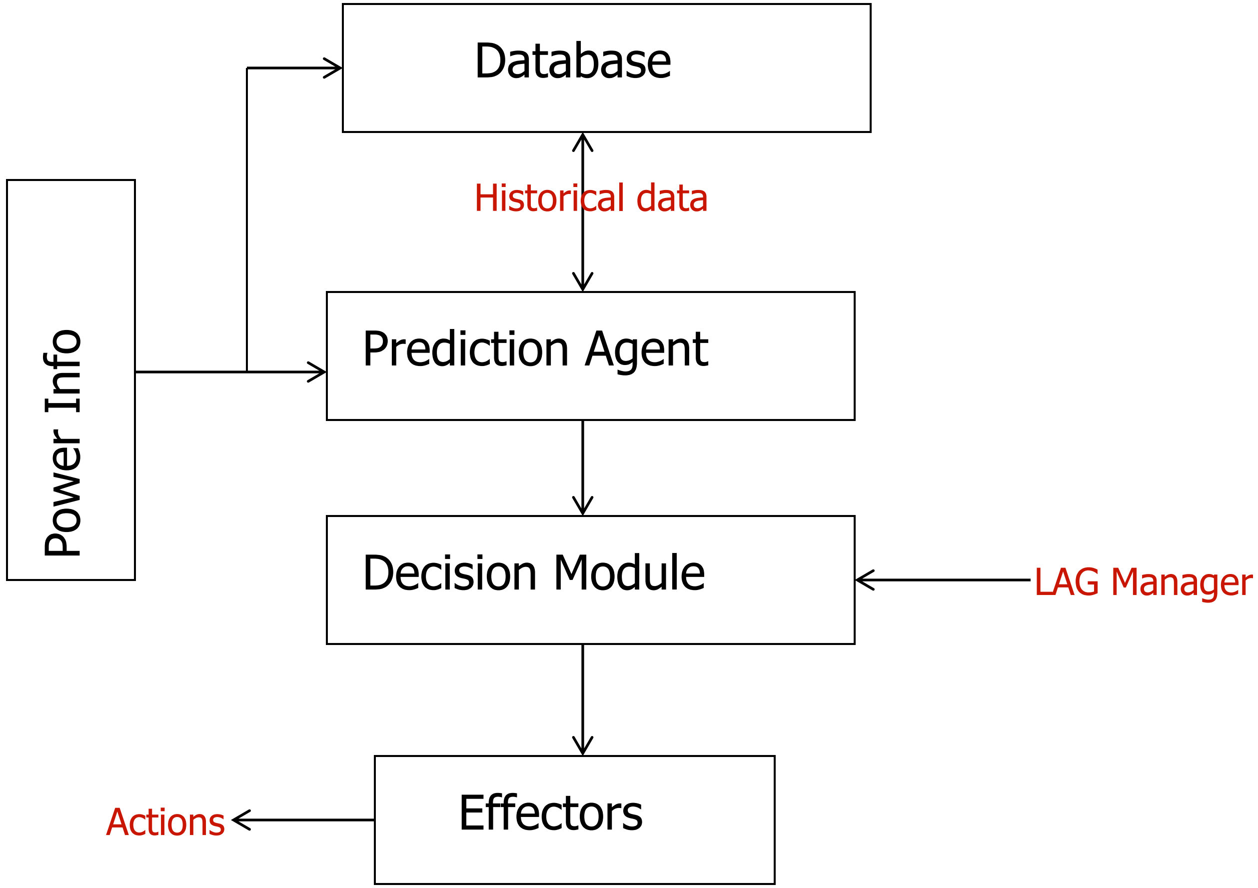
Large Commercial /Industrial (LCI) Customer
Hourly Demand (KW-h) for a week

Hourly data starting at 00:00 Monday

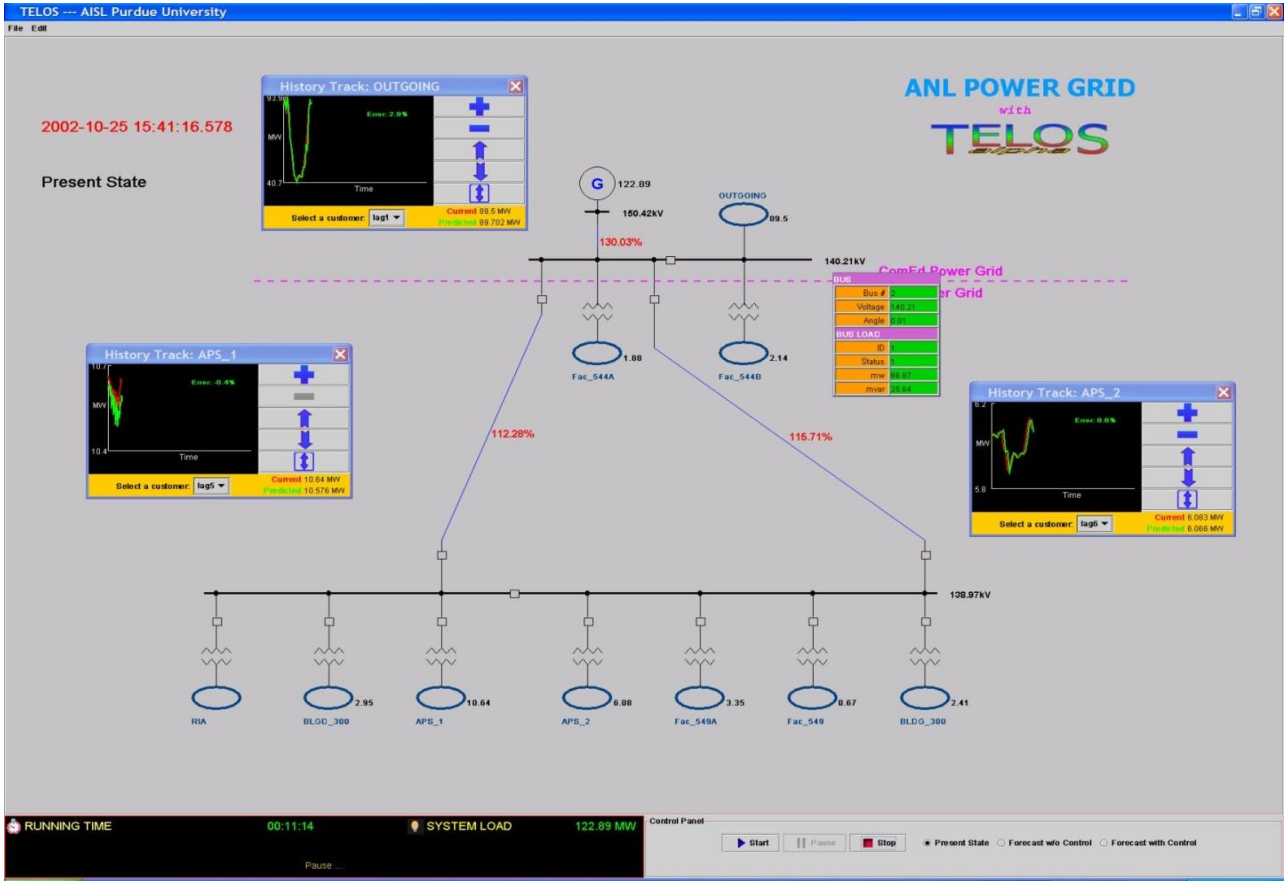


Residential (RSL) Customer
Hourly Demand (KW-h) for a week

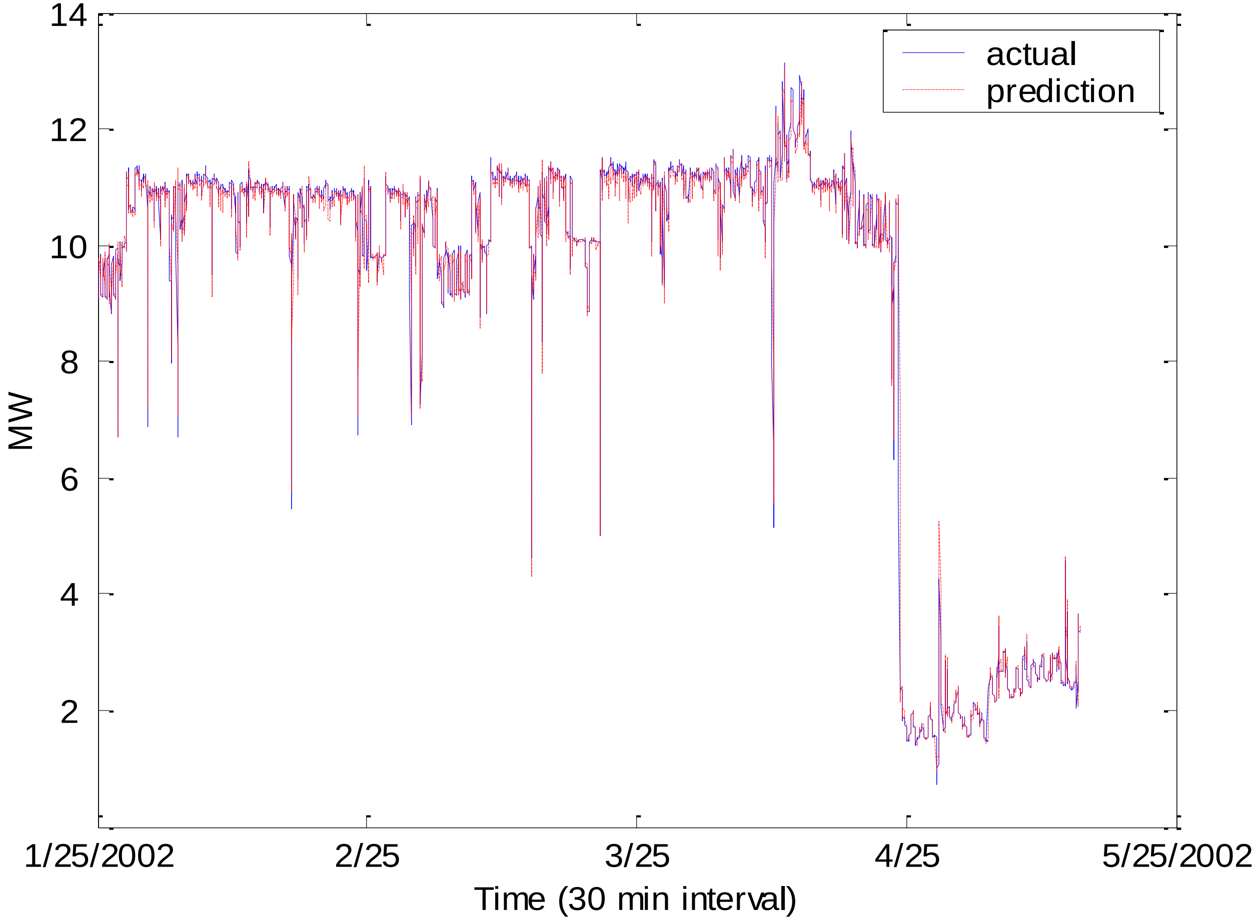
Intelligent Power Meter



TELOS Simulation

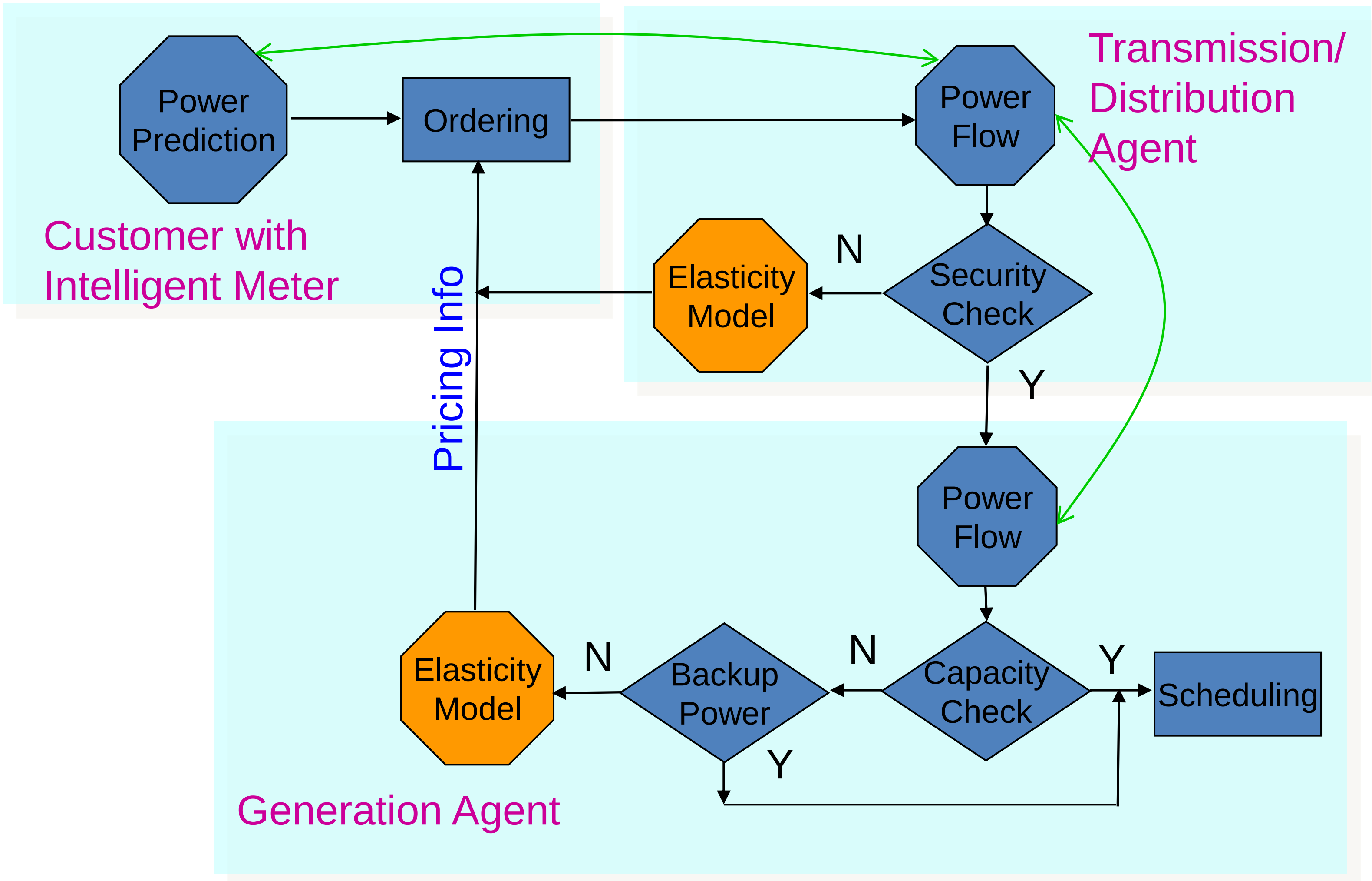


Demand Forecast in TELOS



Argonne National Laboratory (ANL)

Dynamic Scheduling via Elasticity



Summary

- Internet-like energy networks for sustainable global energy utilization may offer the way past Energy Crisis
- All forms of primary energy needed to produce the most easily available energy we have - grid electricity
- Intelligent Systems can provide virtual energy storage (via anticipation) and price-directed demand
- Intelligent systems and energy technology may positively shape a sustainable future through more transparent energy relations