Signposts ...
Traffic management

- Singapore operates congestion pricing
- Singapore has 90% accuracy in predicting traffic congestion
- Dynamically adjusts 1,700 sets of traffic lights to smooth flow
Building automation

- Telenor reduced its electricity usage from 300kWh to 100kWh per m²
- 1,100 workplaces are individually controlled
- Rooms are regulated with 600 multifunctional office nodes with sensors
- 900 valves control heating and ventilation
... to the emergence of a new field

Energy Informatics
Core concept

- Energy + Information < Energy

- Analyzing, designing, and implementing information systems to increase energy efficiency
  - Collection and analysis of energy data sets
  - Optimization of energy distribution networks
  - Optimization of energy consumption systems
Framework
Supply & demand

Supply

Demand

Sensor networks
Flow networks
Information system
Sensitized objects

Eco-goals
- Eco-efficiency
- Eco-effectiveness
- Eco-equity

Stakeholders
- Consumers
- Suppliers
- Governments

Economics

Corporate norms

Regulations

Social norms

Eco-goals
- Eco-efficiency
- Eco-effectiveness
- Eco-equity

Stakeholders
- Consumers
- Suppliers
- Governments

Eco-efficiency
Eco-effectiveness
Eco-equity
Supply and demand

- Two parties to every energy transaction
- A comprehensive solution integrates both sides
- Economics is the common factor on each side
- Regulations mainly impact suppliers
- Changing corporate and social norms will impact suppliers and consumers
Flow network

- A set of connected transport components that support the flow of
  - Continuous matter
    - Electricity
    - Oil
    - Air
  - Discrete objects
    - Vehicle
    - Package
    - Person
- Flows consume energy
US primary energy consumption by source

- Petroleum: 39.8%
  - Percent of Source: 70
  - Percent of Sector: 96
  - Transportation: 29.0%
- Natural Gas: 23.6%
  - Percent of Source: 24
  - Percent of Sector: 44
  - Industrial: 21.4%
- Coal: 22.8%
  - Percent of Source: 9
  - Percent of Sector: 18
  - Residential and Commercial: 10.6%
- Renewable Energy: 6.8%
  - Percent of Source: 2
  - Percent of Sector: 2
  - Electric Power: 40.6%
- Nuclear Electric Power: 8.4%
  - Percent of Source: 100
Sensor network

- A set of spatially distributed devices that report the status of a physical item or environmental condition
  - Temperature
  - Air composition
  - Location and speed of an object
  - Contents of a package in transit
  - Traffic on a link
Sensitized object

- A physical good that a consumer owns or manages and has the capability to sense and report data about its use
- It might also adjust its use of a flow network

The Australian CSIRO Intelligent Energy team has developed a smart fridge capable of maintaining its average temperature while regulating its power consumption from renewable-energy generators.
Information system

- Ties together the elements to provide a complete solution
- Integrates supply and demand for a comprehensive solution
- Provides interfaces for suppliers and consumers
- Automates aspects of the flow network
  - Sense and act mechanisms
Flow networks
Flow networks

Eco-goals
- Eco-efficiency
- Eco-effectiveness
- Eco-equity

Stakeholders
- Consumers
- Suppliers
- Governments

Flow networks
- Sensor networks
- Information system
- Sensitized objects

Arrows indicate relationships and interactions within the system.
Identifying the flows

- Sequences of flows
- Layers of flows
  - Item within a package
  - Package within a container
  - Container within a boat
- Sequences with layers
Optimizing flows

- Criteria
  - Least energy
    - Least distance
  - Smallest fleet
  - Full loads
  - Load/unload time
  - Consistency
Optimizing flows

- Criteria
  - Throughput
  - Energy
  - Emissions
  - Waste
- Static and dynamics
  - Hub and spoke
  - Established infrastructure limits
Optimization

Netherlands Railways used optimization to increase operating efficiency by 6% and save €20 million.

The busiest national railroad in Europe.

Dynamic scheduling to match trains to expected traffic.
Demand management

- Dynamic
  - Electricity distribution
- Scheduled
  - Rooms within buildings
  - Buildings within a campus
Sensors
Flow networks

Supply

Sensor networks

Flow networks

Information system

Demand

Sensitized objects

Eco-goals

Eco-efficiency
Eco-effectiveness
Eco-equity

Stakeholders

Consumers
Suppliers
Governments

Regulations
Economics
Corporate norms

Stakeholders

Consumers
Suppliers
Governments

Regulations
Economics
Social norms

Eco-goals

Eco-efficiency
Eco-effectiveness
Eco-equity

Wednesday, April 7, 2010
# Sensor types and actions

<table>
<thead>
<tr>
<th>Sensor Type</th>
<th>Supply Action</th>
<th>Demand Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed</td>
<td>Measure flow</td>
<td>Control flow</td>
</tr>
<tr>
<td>Mobile</td>
<td>Report status</td>
<td>Change path</td>
</tr>
</tbody>
</table>

*Wednesday, April 7, 2010*
Sensor networks

- Capture rich digital data sets to enable flow network optimization
- How much data at what cost to get a near optimal solution?
- The data granularity problem
  - Location
  - Frequency
  - Measures
Technologies

Zigbee™

Small low-power digital radios
Advanced metering and demand response for the home
Technologies: smart meters

- Wireless communication
  - Report usage
  - Reduce load
  - Connect/Reconnect
- 40 million smart meters in US homes in next three years
The new St. Anthony Falls Bridge crossing the Mississippi River in Minneapolis has a half dozen types of sensors embedded in it. Here’s what they measure:

- **Concrete Strength**: During construction, meters in support columns determined when they were ready to bear weight.
- **Strain**: Two types of devices measure shortening or stretching of the concrete.
- **Movement**: Sensors track movements in expansion joints, which could be caused by temperature changes.
- **Temperature Gauges**: Measure the temperature on the concrete so it can be correlated to changes in curvature of the bridge.
- **Vibrations**: Sensors note changes that could indicate damage to the bridge.
- **Corrosion**: Metal pieces embedded in the travel surface send alerts before salt begins corroding reinforcing steel.
- **Ice**: When conditions are right for ice to form, sprinkler heads in the pavement spread an anti-icing solution.

Sensor network cost USD 1 million (0.5% of the total cost)

Source: BusinessWeek, March 2, 2009
Sensor: Resource status

Parking spaces in San Francisco
Information system

The keystone
Information system

Supply

Sensor networks

Flow networks

Demand

Sensitized objects

Information system

Eco-goals

Eco-efficiency
Eco-effectiveness
Eco-equity

Stakeholders

Consumers
Suppliers
Governments

Regulations
Economics
Corporate norms

Regulations
Economics
Social norms

Eco-goals

Eco-efficiency
Eco-effectiveness
Eco-equity

Stakeholders

Consumers
Suppliers
Governments

Wednesday, April 7, 2010
Information system

- Collect data from the sensor network and feed them into flow optimization algorithms
- Transmits data to controllers in the flow network to dynamically change a network based on the output of the optimization algorithms
Supply information to flow network managers so they can manage and monitor their networks.

Supply information to consumers about the use of the objects within their control.
Manage energy supply and demand to minimize CO$_2$ emissions

Enable consumers to automate or control object usage to reduce energy consumption
Information system

- Supply comparative information to suppliers and consumers so they can benchmark their efforts and set new targets for energy reduction.
- Supply information to governments on flow network performance.
  - Energy Reporting Language.
UPS

En Route to Energy Informatics
UPS case

- Collects data from automotive bus and GPS
  - 4,000 - 5,000 GPS points
  - 200 vehicle related elements
- Linked to DIAD
UPS: Backing event
UPS: An idling event

Wednesday, April 7, 2010
<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Count</th>
<th>Date Min</th>
<th>Date Max</th>
<th>Flash Code</th>
<th>Failure Code</th>
<th>Failure</th>
<th>Controller</th>
<th>Failure Mode</th>
<th>Engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>132044</td>
<td>1</td>
<td>7/1/2009</td>
<td>7/1/2009</td>
<td>134</td>
<td>91</td>
<td>APS or IVS data erratic</td>
<td>Engine</td>
<td>7-Mechanical system not</td>
<td>NAVISTAR T444E</td>
</tr>
<tr>
<td>132044</td>
<td>1</td>
<td>7/1/2009</td>
<td>7/1/2009</td>
<td>135</td>
<td>230</td>
<td>Idle Validation Switch Circuit Fault - PART</td>
<td>Engine</td>
<td>11-Failure mode not identifiable</td>
<td>NAVISTAR T444E</td>
</tr>
<tr>
<td>145822</td>
<td>1</td>
<td>7/1/2009</td>
<td>7/1/2009</td>
<td>P1216</td>
<td>1216</td>
<td>Torque Converter Clutch Stuck On</td>
<td>CHASSIS (C)</td>
<td>0-None</td>
<td>GM 8.1L, 7.3L</td>
</tr>
<tr>
<td>886505</td>
<td>1</td>
<td>7/1/2009</td>
<td>7/1/2009</td>
<td>P0140</td>
<td>140</td>
<td>O2 Sensor Circuit No Activity Detected</td>
<td>POWERTRAIN</td>
<td>0-None</td>
<td>GM 6.0L</td>
</tr>
<tr>
<td>886505</td>
<td>1</td>
<td>7/1/2009</td>
<td>7/1/2009</td>
<td>P0154</td>
<td>154</td>
<td>O2 Sensor</td>
<td>POWERTRAIN</td>
<td>0-None</td>
<td>GM 6.0L</td>
</tr>
<tr>
<td>886505</td>
<td>1</td>
<td>7/1/2009</td>
<td>7/1/2009</td>
<td>P0171</td>
<td>171</td>
<td>Lean Exhaust Indication - O2 Check exhaust</td>
<td>POWERTRAIN</td>
<td>0-None</td>
<td>GM 6.0L</td>
</tr>
<tr>
<td>886505</td>
<td>1</td>
<td>7/1/2009</td>
<td>7/1/2009</td>
<td>P9400</td>
<td>400</td>
<td>Exhaust Gas Recirculation Flow</td>
<td>POWERTRAIN</td>
<td>0-None</td>
<td>GM 6.0L</td>
</tr>
</tbody>
</table>
Triple bottom line

- Social
  - Increased safety
  - Accidents are responsible for 25% of non-recurring congestion
- Environmental
  - Reduced fuel consumption
  - More efficient routes
- Financial
  - Idling time reduced by 15 minutes per day
  - Reduced maintenance
Shift from 80:20 to 70:30
commercial: residential

Gigajoules per 1,000 packages
Two energy flow systems

Telematics

Package flow
Demand management
Information Systems strategies to support green behaviors

- Inform
- Persuade
Information Systems strategies to support green behaviors

- Inform through
  - Tailoring
  - Aggregating
  - Disaggregating
Inform through tailoring

- Provide information to consumers based on a customizable or adaptable set of parameters
Inform through aggregating

- UPS has metrics on
  - Trucks
  - Drivers
  - Customer interactions

 There’s just a slew of data coming out all the time… There’s just this pile of data that means nothing to anybody

Jack Levis, Director, Package Process Management

- Insights derived from marrying the three disparate data sets
Inform through *disaggregating*

- Electricity consumption measured for large units
- Disaggregate energy use to individual components
- Plogg
  - Reports electricity consumption at the outlet level
  - Communicates with a range of devices
  - Can switch On and Off remotely
Information Systems strategies to support green behaviors

- Persuade through
  - Suggesting
  - Comparing
  - Self-monitoring
  - External-monitoring
Persuade through suggesting

- Persuade consumers by suggesting…
  - What
  - When
  - How
Inform through suggesting

What to purchase...

Integrates into your web browser

Change between search engines any time!

Wednesday, April 7, 2010
Inform through suggesting

- When to act
- UPS’s telematics project suggests when
  - To replace components
    - From time-based maintenance to condition-based maintenance
  - To turn on the engine
    - An average decrease of vehicle idle time of 15 minutes per driver per day
Inform through suggesting

- How to perform a given process

- Go paperless

Help the environment by reducing paper consumption

- Purchase carbon offsets to reduce the environmental impact of your trip
When it comes to persuading people to conserve energy, the message “everybody else is doing it” works better than trying to appeal to people's sense of social responsibility, desire to save money or even to their hope of safeguarding the earth for future generations.

American Psychological Association, 2007
Persuade through comparing

- Green Engage
  - Expected saving of $200 million in electricity costs across the company's entire portfolio

Conserve and Save Home Energy Report
Persuade through self-monitoring

Dashboards

The norm is for savings from direct feedback (immediate, from the meter) to range from 5-15%. The role of the meter is to provide a clearly-understood point of reference for improved billing and for display.

Environmental Change Institute, 2006
Persuade through external monitoring

- Pay-as-you-drive

- *Research expects widespread adoption of PAYD policies to reduce driving by 10-20%, resulting in significant decreases in greenhouse gas emissions and resulting global climate change and air pollution.*

- Fundburg, Grant, and Coe, 2004
Supply & demand integration
Supply & demand

Eco-goals
- Eco-efficiency
- Eco-effectiveness
- Eco-equity

Stakeholders
- Consumers
- Suppliers
- Governments

Economics
- Regulations
- Corporate norms

Sensor networks
Flow networks
Information system
Sensitized objects

Eco-goals
- Eco-efficiency
- Eco-effectiveness
- Eco-equity

Stakeholders
- Consumers
- Suppliers
- Governments

Economics
- Regulations
- Social norms

Wednesday, April 7, 2010
Reduce demand to match supply

- Adjust electricity demand based on supply
  - A public-private partnerships will create an open, global standard for home appliances to transmit and receive signals by 2010
  - All Whirlpool appliances will be Smart Grid compatible by 2015
Change demand based on supply

- Adjust route based on traffic congestion
  - Acura RL Navigation system continuously updates traffic information
- Can suggest alternative routes based on current traffic levels
Time shift demand to match supply

- Road congestion pricing
- Airline revenue management
Mutually adjusting supply and demand

- Vélib
- Self-service bike rental
- All bikes identified and bike racks online
- City moves bikes based on demand
- Customers can see number of bikes at nearby racks via their cell phone
Forces for change
Forces for change
Stakeholders

- Consumers
- Suppliers
- Governments
Eco-forces

- Eco-efficiency
- Eco-equity
- Eco-effectiveness
Eco-efficiency

- The delivery of competitively-priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life-cycle to a level at least in line with the earth’s carrying capacity

- Eco-efficiency improves profits
- An economic force on suppliers
- Suppliers will push for demand management
Eco-equity

- Equity between peoples and generations and, in particular, the equal rights of all peoples to environmental resources
- Political horizons are too short but still might see some government regulations
- Likely to be reflected in changing social norms of consumers and corporate norms
Eco-effectiveness

- Transformation to new business models
  - Ultimate solution
  - Mindset shift
  - Cradle-to-cradle
The power of integrated problem solving

52 stories
4 watts per square meter
Typically 15 - 19 watts per square meter
Savings are 70% beyond original benchmark
Actions
Actions for CIOs

- Get prepared to take on energy informatics
  - Energy economics
  - Building automation
  - Management science
  - Sensor network design
Actions for CIOs: Supply side

- Identify your major flow networks
- Select a non-critical flow network or a portion of a critical flow for a pilot
- Initially justify on eco-efficiency
- Design and implement a sensor network
- Design and build the IS
  - Embed optimization algorithms
- Implement the redesigned flow network
Actions for CIOs: Demand side

- Identify objects to sensitize
- Design and implement an IS that leverages the selected strategy and integrate sensitized objects
  - Inform and/or persuade
- Sell to consumers with green marketing
- Integrate with supply side IS
Actions of industry

- Develop standards for sensitized devices
- Develop standards for describing flow networks
  - Platform for coordination and optimization
Questions