Context: Cities with 10 million people

- By 2020, more than 30 mega-cities in the now less-developed world. By 2050, nearly 60 such cities.

- Increased population creates need for more resources. World's electricity supply will need to triple by 2050 to keep up with demand, necessitating nearly 10,000 GW of new generating capacity.
Goals and Recommendations (IEEE, Jan. 2009)

• Building a stronger and smarter electrical energy infrastructure
  – Transforming the Network into a Smart Grid
  – Developing an Expanded Transmission System
  – Developing Massive Electricity Storage Systems

• Breaking our addiction to oil by transforming transportation
  – Electrifying Transportation: Plug-In Hybrid Electric Vehicles
  – Developing and Using Alternative Transportation Fuels

• Greening the electric power supply
  – Expanding the Use of Renewable Electric Generation
  – Expanding Nuclear Power Generation
  – Capturing Carbon Emissions from Fossil Power Plants

• Increasing energy efficiency
Enabling a Stronger and Smarter Grid

• Smart Grid Challenges/Opportunities:
  – Infrastructure for Generation/Transmission/Distribution Systems
  – Infrastructure for Smart Customer Interface
  – Distribution Automation
  – Smart metering improves load models and profiles
  – Device monitoring and self-healing diagnostics
  – Communication infrastructure provides opportunities for monitoring and diagnostics
  – Distributed Sensing and Control
  – Alternative Smart Grid Architectures
  – Infrastructure Security: Controls, Communications and Cyber Security
  – Markets and Policy
  – Distributed generation and storage adds complexity

Enabling a Stronger and Smarter Grid

Real-time Simulation and Contingency Analysis
Integration of Distributed Generation, Massive Storage and Alternate Energy Sources
Electrifying Transportation: Plug-In Hybrid Electric Vehicles and Integration
Self-Healing Wide-Area Protection and Islanding
Asset Management and On-Line Equipment Monitoring
Demand Response and Dynamic Pricing
"Dollars and Watts" Participation in Energy Markets

Transforming Society

The vast networks of electrification are the greatest engineering achievement of the 20th century
– U.S. National Academy of Engineering
Context: R&D Expenditures*

- Analyses of DOE data shows that over the 25 years from FY 1978 to FY 2004, US government appropriations for ER&D fell from 6.4B to $2.75B in constant year-2000 dollars, a nearly 60% reduction.

- The part of these appropriations devoted to applied energy-technology RD&D fell from $6.08 B to $1.80B.

Declining Public Support for Energy RD&D during the 25-years 1978-2004

Gallagher and Sagar, 2004
Private Sector Energy RD&D

An analysis of less complete private-sector data indicates a drop by about a factor of three in the private sector funding for the indicated purposes during the same period.

Dooley and Runci, 2004

Capital Invested as % of electricity revenue
Increasing Outage Events: Transmission Investment

Transmission investment ($) since 1975

Transmission capacity margin in every NERC region since 1982

Transmission investment lags load growth and will remain very difficult in the future due to environmental, political, and cost issues.

Utility construction expenditures

Source: "Historical Statistics of the Electric Utility Industry" and "EED Statistical Yearbook". EED.

- **1991-1995**
  - 66 Occurrences over 100 MW
  - 798 Average MW Lost
  - 41 Occurrences over 50,000 Consumers
  - 355,204* Average Consumers Dropped

- **1996-2000**
  - 76 Occurrences over 100 MW
  - 1,067 Average MW Lost
  - 58 Occurrences over 50,000 Consumers
  - 409,854* Average Consumers Dropped

Increasing frequency and size of US power outages 100 MW or more (1991-1995 versus 1996-2000), affecting 50,000 or more consumers per event.

Data courtesy of NERC’s Disturbance Analysis Working Group database

*Note: Annual increase in load (about 2%/year) and corresponding increase in consumers should be taken into account.

**Historical Analysis of U.S. outages (1991-2005)**

- **1991-2005**
  - 66 Occurrences over 100 MW
  - 41 Occurrences over 50,000 Consumers
  - 140 Occurrences over 100 MW
  - 92 Occurrences over 50,000 Consumers

Result: Large blackouts are growing in number and severity.

*Analyzing 2006 outages:
- 24 Occurrences over 100 MW
- 34 Occurrences over 50,000* Consumers

Data courtesy of NERC’s Disturbance Analysis Working Group database

*Note: Annual increase in load (about 2%/year) and corresponding increase in consumers should be taken into account.
Power Law Distributions: Frequency & impacts of major disasters

Hurricane and Earthquake Losses 1900–1989
Flood Losses 1986–1992
Electric Network Outages 1984–2000

Cumulative Number of Events per Year

Loss Per event (million 1990 dollars)

- Hurricanes
  - D = -0.98
  - Aug. 13, 1996
- Earthquakes
  - D = -0.41
- Floods
  - D = -0.74

A Toll Felt Throughout the U.S. Economy:
Over $100B per year

Total Annual Cost of Power Outages and PQ Disturbances by Business Sector

TOTAL $119 - $188 Billion

Source: Primen Study: The Cost of Power Disturbances to Industrial & Digital Economy Companies
**Context: Transmission investment in the United States and in international competitive markets**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>New Zealand</td>
<td>22.0</td>
<td>1</td>
</tr>
<tr>
<td>England &amp; Wales (NGT)</td>
<td>16.5</td>
<td>1</td>
</tr>
<tr>
<td>Denmark</td>
<td>12.5</td>
<td>2</td>
</tr>
<tr>
<td>Spain</td>
<td>12.3</td>
<td>1</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>12.0</td>
<td>1</td>
</tr>
<tr>
<td>Norway</td>
<td>9.2</td>
<td>1</td>
</tr>
<tr>
<td>Poland</td>
<td>8.6</td>
<td>1</td>
</tr>
<tr>
<td>Finland</td>
<td>7.2</td>
<td>1</td>
</tr>
<tr>
<td>United States</td>
<td>4.6 (based on representative data from EEI)</td>
<td>450 (69 in EEI)</td>
</tr>
</tbody>
</table>

Source: IEEE PES, 2006

**Context: New patterns in power delivery**

Map adapted from the U.S. DOE National Electric Transmission Congestion Study
Context: New patterns in power delivery

- More efficient to move electrical power through the transmission system than to ship fuels the same distance;

- Transition from fossil fuel-based power generation to fluctuating energy sources such as wind, sun, and wave power introduces challenging demands on the storage, dispatch, operation and integration with the power grid;

- Integration of energy resources and demands will require interconnected transmission network, a **Smart Grid**, that is:
  - **Intelligent**: autonomous digital system identifies surges, outages → **Predictive** rather than reactive, to prevent emergencies
  - **Resilient**: “self-healing” and adaptive - instantaneous damage control
  - **Reliable**: dynamic load balancing
  - **Flexible**: accommodates new off-grid alternative energy sources
  - **Interactive** with consumers and markets
  - **Optimized** to make best use of resources and equipment
  - **Integrated**, merging monitoring, control, protection, maintenance, EMS, DMS, marketing, and IT
  - **Secure**: less vulnerable to attacks and destabilizers

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Enabling a Stronger Grid

Map adapted from the U.S. DOE National Electric Transmission Congestion Study
Context: New Challenges

- Economic dispatch
- Strong correlation between power flow and demand
- Market-based dispatch
- Poor correlation between power flow and demand

Source: EPRI/DOD Complex Interactive Networks/Systems Initiative (CINSI)

Definition: Self Healing Grid

• What is “self healing”?
  – A system that uses information, sensing, control and communication technologies to allow it to deal with unforeseen events and minimize their adverse impact ...

• Why is self healing concept important to the Electric Power Grid and Energy Infrastructure?
  – A secure “architected” sensing, communications, automation (control), and energy overlaid infrastructure as an integrated, reconfigurable, and electronically controlled system that will offer unprecedented flexibility and functionality, and improve system availability, security, quality, resilience and robustness.
Will today’s electricity supply system be left behind as an industrial relic of the 20th century, or become the critical infrastructure supporting the digital society, a smart self-healing grid?
What are we doing about it?

Overview of my research areas (1998-2003):
Initiatives and Programs I developed and/or led at EPRI

<table>
<thead>
<tr>
<th>Initiative/Program</th>
<th>1999-2001</th>
<th>Y2K2000-present</th>
<th>2002-present</th>
<th>2001-present</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPRI/DoD Complex Interactive Networks (CIN/SI)</td>
<td>EPRI/DoD Complex Interactive Networks (CIN/SI)</td>
<td>Enterprise Information Security (EIS)</td>
<td>Infrastructure Security Initiative (ISI)</td>
<td>Consortium for Electric Infrastructure to Support a Digital Society (CEIDS)</td>
</tr>
</tbody>
</table>
2. IntelliGrid™
3. Integrated Electric Communications System
4. Architecture Fast Simulation and Modeling |
2. Vulnerability Assessments
3. Red Teaming Secure Communications |
Recent Directions: EPRI/DOD Complex Interactive Network/Systems Initiative

“We are sick and tired of them and they had better change!”
Chicago Mayor Richard Daley on the August 1999 Blackout

Complex interactive networks:

- **Energy infrastructure**: Electric power grids, water, oil and gas pipelines
- **Telecommunication**: Information, communications and satellite networks; sensor and measurement systems and other continuous information flow systems
- **Transportation and distribution networks**
- **Energy markets, banking and finance**

1999-2001: $5.2M / year — Equally Funded by DoD/EPRI

Develop tools that enable secure, robust and reliable operation of interdependent infrastructures with distributed intelligence and self-healing abilities
CIN/SI Funded Consortia

108 professors and over 240 graduate students in 28 U.S. universities were funded: Over 420 publications, and 24 technologies extracted, in the 3-year initiative

- Defense Against Catastrophic Failures, Vulnerability Assessment
- Intelligent Management of the Power Grid
- Modeling and Diagnosis Methods
- Minimizing Failures While Maintaining Efficiency / Stochastic Analysis of Network Performance
- Context Dependent Network Agents
- Mathematical Foundations: Efficiency & Robustness of Distributed Systems

Background: The Self Healing Grid
Saving systems from collapse: The Case of the Missing Wing (1983-1997)

Goal: Optimize controls to compensate for damage or failure conditions of the aircraft

Accomplishments in the IFCS program

- The system was successfully test flown on a test F-15 at the NASA Dryden Flight Research Center:
  - Fifteen test flights were accomplished, including flight path control in a test flight envelope with supersonic flight conditions.
  - Maneuvers included 4g turns, split S, tracking, formation flight, and maximum afterburner acceleration to supersonic flight.
- Stochastic Optimal Feedforward and Feedback Technique (SOFFT) continuously optimizes controls to compensate for damage or failure conditions of the aircraft.
- Flight controller uses an on-line solution of the Riccati equation containing the neural network stability derivative data to continuously optimize feedback gains.
Self-healing Grid (1998-present)

Building on the Foundation:
• Anticipation of disruptive events
• Look-ahead simulation capability
• Fast isolation and sectionalization
• Adaptive islanding
• Self-healing and restoration

Local area grids (LAG)
In many complex networks, the human participants themselves are both the most susceptible to failure and the most adaptable in the management of recovery.

“... not to sell light bulbs, but to create a network of technologies and services that provide illumination...”

The Energy Web:

“The best minds in electricity R&D have a plan: Every node in the power network of the future will be awake, responsive, adaptive, price-smart, eco-sensitive, real-time, flexible, humming - and interconnected with everything else.”

-- Wired Magazine, July 2001

http://www.wired.com/wired/archive/9.07/justice.html
Macro-Level Modeling: The U.S. Power Grid

MODEL REDUCTION

Simplified models

Variable levels of details

Lines, loads, generators are dynamic

Detailed models

MODEL REFINEMENT

Low-resolution model

Look-Ahead Simulation Applied to Multi-Resolution Models

- Provides faster-than-real-time simulation
  - By drawing on approximate rules for system behavior, such as power law distribution
  - By using simplified models of a particular system

- Allows system operators to change the resolution of modeling at will
  - Macro-level (regional power systems)
  - Meso-level (individual utility)
  - Micro-level (distribution feeders/substations)
Sensing and Control Strategies

• Centralized

• Distributed

• Perfectly decentralized

The Self-Healing Grid

Dependability/Robustness/Self-Healing (min-hours)
(1sec)

Autonomy/Fast Control (msec)

Knowledge/Decision Exchange

Reconfiguration Agents
Planning Agents
Restoration Agents

Hidden Failure Monitoring Agents
Event Identification Agents

Vulnerability Assessment Agents

Event Identification Agents

Model Update Agents

Fault Isolation Agents

Frequency Stability Agents

Protection Agents

Generation Agents

Inhibitor Signal

Command Interpretation Agents

Consistency

Consistency

Inputs

Outputs

Infrastructure System

5:30:00
EPRI/DoD CIN/S Initiative
The Self-Healing Grid

Adaptive Islanding

Past Scheme

New Scheme
EPRI’s Reliability Initiative-- Sample Screen of Real-time Security Data Display (RSDD)

Situation Awareness Tool (SAT)
Situation Awareness Tool (SAT)

Prioritization: Security Index

General
1. Corporate culture (adherence to procedures, visible promotion of better security, management security knowledge)
2. Security program (up-to-date, complete, managed, and includes vulnerability and risk assessments)
3. Employees (compliance with policies and procedures, background checks, training)
4. Emergency and threat-response capability (organized, trained, manned, drilled)

Physical
1. Requirements for facilities (critical list, inventory, intrusion detections, deficiency list)
2. Requirements for equipment (critical list, inventory, deficiency list)
3. Requirements for lines of communications (critical list, inventory, deficiency list)
4. Protection of sensitive information

Cyber and IT
1. Protection of wired networks (architecture analysis, intrusion detection)
2. Protection of wireless networks (architecture analysis, intrusion detection, penetration testing)
3. Firewall assessments
4. Process control system security assessments (SCADA, EMS, DCS)
Context: IT interdependencies and impact

**Dependence on IT**: Today’s systems require a tightly knit information and communications capability. Because of the vulnerability of Internet communications, protecting the system will require new technology to enhance security of power system command, control, and communications.

**Increasing Complexity**: System integration, increased complexity: call for new approaches to simplify the operation of complex infrastructure and make them more robust to attacks and interruptions.

**Centralization and Decentralization of Control**: The vulnerabilities of centralized control seem to demand smaller, local system configurations. Resilience rely upon the ability to bridge top–down and bottom-up decision making in real time.

**Assessing the Most Effective Security Investments**: Probabilistic and dynamic assessments can offer strategic guidance on where and how to deploy security resources to greatest advantage.

Cyber Threats to Controls

![Perceived Threats to Power Controls](image)

Information Networks for On-Line Trade, Security and Control

Assessment & Prioritization: A Composite Spider Diagram to Display Security Indices
Energy Infrastructure, Economics, Efficiency, Environment, Secure Communications and Adaptive Dynamic Systems

Economics ↔ Electric Power

“Prices to Devices”

Complex, highly nonlinear infrastructure
Evolving markets, rules and designs

“If you measure it you manage it → if you price it you manage it even better”… Technologies, Designs, Policies, Options, Risks/Valuation

Adaptive Systems (self-healing)

Society (including Policy & Environment)

EPRI/DOD Complex Interactive Networks Initiative

• Overall results (theoretical and applied) for increased dynamic network reliability and efficiency:
  - Identification, characterization and quantification of failure mechanisms
  - In Silico testing of devices and policies in the context of the whole system -- the grid, markets, communication and protection
  - Fundamental understanding of interdependencies, coupling and cascading
  - Development of predictive models
  - Development of prescriptive procedures and control strategies for mitigation or/and elimination of failures
  - Design of self-healing and adaptive architectures
  - Trade-off between robustness and efficiency

• Extracted the most promising technologies for testing with real data and further development.

• However many challenges and opportunities persist →
Understanding Complex Dynamical Systems

... Systems' operations, mathematical foundations, and guidance on how to measure and adapt to disturbances:

System is characterized as having multiple states, or “modes,” during which specific operational and control actions/reactions are taking place:

- **Normal mode**: economic dispatch, load frequency control, maintenance, forecasting, etc.;
- **Alert mode**: red flags, precursor detection, reconfiguration and response;
- **Emergency/Disturbance mode**: stability, viability, and integrity -- instability, load shedding, etc.;
- **Restorative mode**: rescheduling, resynchronization, load restoration, etc.

Another Persisting Challenge

- Enhancing Reliability and Security of Network Operation via quantification of the system state and its “direction/speed/momentum” toward a major failure
- Making Network Availability (quick restoration) a key requirement
- Introducing Quality of Service as an additional constraint
- Ultimately, enabling operators to act more efficiently and with greater confidence in difficult (sometimes unclear, unexpected or even conflicting) circumstances

Which trajectories lead to catastrophic failures?
An Assessment Methodology

- Infrastructure Disruption
  - Stable Operation Subspace

1/size

Disruption of nearly Infinite size & duration 1/Duration

Identify/"measure" destabilizing trajectories and impacts

Foresight

Renewables/infrastructure integration, Electrification of transportation
Smart Grid Field Data

Tremendous amount of data coming from the field in the near future - paradigm shift for how utilities operate and maintain the grid

One of my research areas: S&T Assessment, Scan & Map
(April 2005-Feb 2006; Galvin Electricity Initiative)
- **“Wind power could blow electric grid”:** Utilities and developers are poised to more than quadruple the amount of wind power in the Northwest, but a study shows the electric grid might not be able to handle it all, *The Oregonian* reported. The federal Bonneville Power Administration said in its assessment it has space on the grid to add only one-third of the planned 4,716 megawatts without additional power lines, the newspaper reported. A total of 6,000 megawatts of wind would supply about 8% of the Northwest’s electricity needs, according to the BPA report. "A resource isn’t very valuable unless you can deliver it,” Elliot Mainzer, a transmission manager with the power agency, told *The Oregonian*. Bringing lines from the current grid to new wind farms costs up to $3 million a mile…"

(July 22, 2008)

- **“GM, utilities team up on electric cars”:** Partnership aims to tackle issues that will crop up when electric vehicles are rolled out... General Motors Corp. has joined with more than 30 utility companies across the U.S. to help work out electricity issues that will crop up when it rolls out new electric vehicles in a little more than two years.”

---

**Full Fuel Cycle Efficiency Comparison**

<table>
<thead>
<tr>
<th>Type</th>
<th>Efficiency</th>
<th>Miles</th>
<th>Btu/mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plug-in Hybrid</td>
<td>0.29–0.47</td>
<td>2116</td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>0.84</td>
<td>4115</td>
<td></td>
</tr>
<tr>
<td>Full Fuel Cycle Efficiency</td>
<td>0.31–0.50</td>
<td>1631–2185</td>
<td>2161-2185</td>
</tr>
</tbody>
</table>
Hybrid Vehicle Efficiency

Gas tank → Engine (15-20%) → Transmission (90-95%) → Driveline (95%)

Battery → Motor (85-95%) → Gasoline: 13-18% Efficient

Electric: 62-77% Efficient

Market Transformation of Electric Drive Vehicles

Non-Competing - Non-Redundant Vehicle Technologies

- Electric Vehicles (2000)
- Hybrid Vehicles (2005)
- Plug-In Hybrids (2010)
- Plug-In Fuel Cell Hybrids (2015)
- Fuel Cell Vehicles

Source: EPRI
Our Goal...Enabling the Future

Infrastructure integration of microgrids and diverse generation and storage resources into a system of a smart self-healing grid

SMART GRID
A vision for the future—a network of integrated microgrids that can monitor and heal itself.

Smart Grids and Local Energy Networks

Source: EPRI

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Distribution Operations of the Future

**Utility Operations**
- Advanced Monitoring, Communications & Control
- Energy Storage

**Customer Premise**
- Advanced Monitoring, Communications & Control
- Distributed Generation & Storage
- Smart End-Use Devices
  - In-home monitoring
  - "Smart" Thermostats
  - Pool Pumps
  - HVAC Systems

**Distribution Operations**
- Dynamic Systems Control
- Outage Management
- Remote Monitoring & Control of Distribution Assets
- Data Management

**Customer Portal/Meter**
- Energy Storage
- Advanced Monitoring, Communications & Control

Enabling a Stronger and Smarter Grid

**SMART GRID**
- Real-time Simulation and Contingency Analysis
- Integration of Distributed Generation, Massive Storage and Alternate Energy Sources
- Electrifying Transportation: Plug-In Hybrid Electric Vehicles and Integration
- Self-Healing Wide-Area Protection and Islanding
- Asset Management and On-Line Equipment Monitoring
- Demand Response and Dynamic Pricing
- "Dollars and Watts" Participation in Energy Markets

**Generation**
- Solar panels

**Transmission**
- Smart appliances
- Can be shifted to off

**Distribution**
- Can be shifted to off

**Customers**
- Can be shifted to off

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Enabling a Stronger and Smarter Grid

• Smart Grid Challenges/Opportunities:
  – Infrastructure for Generation/Transmission/Distribution Systems
  – Infrastructure for Smart Customer Interface
  – Distribution Automation
  – Smart metering improves load models and profiles
  – Device monitoring and self-healing diagnostics
  – Communication infrastructure provides opportunities for monitoring and diagnostics
  – Distributed Sensing and Control
  – Alternative Smart Grid Architectures
  – Infrastructure Security: Controls, Communications and Cyber Security
  – Markets and Policy
  – Distributed generation and storage adds complexity
Bottom Line:

“Only three things happen naturally in organizations: *friction, confusion and underperformance*. Everything else requires leadership.”

-- Peter Drucker

Enabling a Stronger and Smarter Grid:

- Broad range of R&D including end-use and system efficiency, electrification of transportation, stronger and smarter grid with massive storage

- Sensing, Communications, Controls, Security, Energy Efficiency and Demand Response *if architected correctly* could assist the development of a smart grid

- Smart Grid Challenge/Opportunity areas include:
  - Distributed Control
  - Grid Architectures
  - Cyber Security
May others benefit from your lead.

Thank you

Selected References

Downloadable at: http://umn.edu/~amin


"Powering the 21st Century: We can -and must- modernize the grid," IEEE Power and Energy Magazine, pp. 93-95, March/April 2005

For the Good of the Grid

by S. Massoud Amin

The electric utility industry is the main driver of advanced technology. Developing more efficient and reliable power systems is essential to the functioning of the economy, both in terms of economic growth and environmental sustainability. This involves the integration of renewable energy sources into the grid, which presents both challenges and opportunities. The Smart Self-Healing Grid is an innovative solution that aims to address these challenges, providing increased efficiency and reliability while ensuring the security and sustainability of the system. It is an important step towards a more efficient and resilient electric power network, capable of adapting to changing conditions and maintaining stability. This approach, developed by Massoud Amin and Phillip Schewe, is a testament to the potential of technology to transform the way we generate and distribute electricity.
Bigger picture: challenges...

• Development of advanced Computers, Communications, & Control networks overlay the power network,
• Knowing what is happening- Satellite-based WAMS
• Understanding what constitutes a problem- Dynamic Stability Analysis, visualization tools
• Understanding the “true” dynamics soon enough to do something about it- Faster analysis, look-ahead simulation,…
• Determining what actions could solve the problem- Contingency plans, and risk management
• Implementing the solution- Control devices/systems; alternate path options

... require basic research to develop fundamental solutions...

• Intelligent sensors as elements in real-time data base; sensor interface to multi-resolutional models? Metrics?
• Increased dependence on information systems (e.g., software as the glue among various subsystems/tasks)
• Dependability/robustness is the key; V&V remains a big challenge
• Effect of market structures, distributed generation, other new features on above issues
• Designing/Evolving a robust system - Complexity, distributed sensing, control and adaptation
Related on-going R&D include

- EPRI: Intelligrid, Fast Simulation and Modeling
- Initiatives at several utilities, including Xcel, AEP, Austin Energy, ISOs, etc.)

- Energy Bill passed in December 2007: Title XIII Smart Grid, Sections 1301 -1309
  - Establishes a statement of policy supporting modernization of the grid;
    authorizes a biennial status report and survey of barriers to modernization

- US Department of Energy: Gridwise, Modern Grid, Next Generation Grid Initiatives

- University of Minnesota Center for Smart Grid Technologies

- Smart Grid Newsletter
Meeting either objective will require improvements in supply-side emissions and reduction in consumption.

Summary of numbers: Direct Spending

Total Direct Spending for Renewable Energy and Energy Efficiency: The bill provides $16.8 billion in direct spending for renewable energy and energy efficiency programs over the next ten years.

Grid Development: The bill provides $4.5 billion to modernize the nation’s electricity grid with smart grid technology. The bill increases federal matching grants for the Smart Grid Investment Program from 20% to 50%.

R&D, Demonstration Projects: The bill provides $2.5 billion for renewable energy and energy efficiency R&D, demonstration and deployment activities.

Federal Power Marketing Administrations: The bill provides $6.5 million for capital investments by certain federal power marketing administrations in electric power transmission systems.

Advanced Battery Grants: The bill provides $2 billion for grants for the manufacturing of advanced batteries and components. This includes the manufacturing of advanced lithium ion batteries, hybrid electrical systems, component manufacturers, and software designers.

Defense Energy and Efficiency Programs: The bill provides $300 million to the DOD for the purpose of research, testing and evaluation of projects to energy generation, transmission and efficiency. The bill provides an additional $100 million for Navy and Marine Corps facilities to fund energy efficiency and alternative energy projects.

Study of Electric Transmission Congestion: The bill requires the Secretary of Energy to include a study of the transmission issues facing renewable energy in the pending study of electric transmission congestion that is due to be issued in August 2009.
Summary of numbers: Tax Incentives

Three-Year Extension of PTC: The bill provides a three-year extension of the Production Tax Credit (PTC) for electricity derived from wind facilities through December 31, 2012, as well as for geothermal, biomass, hydropower, landfill gas, waste-to-energy and marine facilities through December 31 2013.

Investment Tax Credit (ITC) Accessible to All Renewable Energy: The bill provides project developers of wind, geothermal, biomass and other technologies eligible for the PTC, the option of instead utilizing the 30% ITC that previously only applied to solar and other clean technology projects.

Advanced Energy Manufacturing Credits: The bill provides $2 billion worth of energy related manufacturing investment credits at a 30% rate. These credits apply to projects creating or retooling manufacturing facilities to make components used to generate renewable energy, storage systems for use in electric or hybrid-electric cars, power grid components supporting addition of renewable sources, and equipment for carbon capture and storage (CCS).

Plug-in Electric Drive Vehicle Credit: The bill increases the tax credit for qualified plug-in electric drive vehicles for the first 200,000 placed in service. The base amount of the credit is $2500. Batteries with at least 5 kilowatt hours of capacity have a credit of $2917. The credit is further increased by $417 for every kilowatt hour in excess of 5 kilowatt hours, but cannot exceed $5000. The credit is allowed to be taken against the alternative minimum tax.

Macroeconomic Rationale

1. Endogenous growth models - theoretical support for domestic technology creation

2. \[ Y = f(R, K, H), \text{ where:} \]
   - \[ Y = \text{GDP} \]
   - \[ R = \text{R&D} \]
   - \[ K = \text{physical capital} \]
   - \[ H = \text{human capital} \]

3. GDP growth: a) Velocity and proportion of R, K, H, and b) available and affordable energy: determinants of success