Insights or Confusion: Analysis of Climate and Energy Systems

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World Energy Supply under BAU

2006

- Oil 34%
- Gas 21%
- Coal 26%
- Nuclear 6%
- Renewables 13%

55% increase in consumption

2030

- Oil 30%
- Gas 22%
- Coal 29%
- Nuclear 5%
- Renewables 14%

Source: IEA/OECD, World Energy Outlook 2008, page 78, table 2.1

2006 consumption 11,700 MBOE
World Energy Futures…not BAU

450ppm World Energy Projections - 2030

IEA World Energy Outlook, 450ppm CO2eq stabilization Scenario.
14360 MBTOE, 22% increase vs 2006
Energy Economic Environmental Modeling

Highly Certain
NOW
Site Specific

Distances/Geospacial

Uncertainty

Highly Uncertain
Decades to Millennia
National to Global

Time
Comparing Integrated Assessment Results

Integrated Assessment Models

- Pull from energy system and technology model results and their underlying assumptions

- Structure of model and “philosophical approach” of model greatly influence forecasts

- Which of these assumptions should be challenged?
Integrated Global System Model (IGSM)

Source: Massachusetts Institute of Technology (MIT)
Primary Energy: 167 GtCO₂-e

Nuclear power and non-biomass renewables converted from direct equivalents to primary energy at a ratio of 3:1
A Range of Possible Futures...

Fossil fuel price assumptions for the scenario year range from:
- Oil: $21 - $100 per bbl
- Coal: $20 - $25 per ton
- Natural Gas: $4 - $8 per mcf

Projection Year

- Laissez-Faire: Minimal policy, slow technological change, greater reliance on fossil fuels.
- Moderate: Moderate policy & technological change.
- Progressive: Progressive policy change & rapid technological advancement.
Strategic Energy Analysis

NREL integrates and analyzes technical and economic information to improve understanding of the value of energy solutions. Strategic energy analysis examines several dynamic factors including global, national, and local markets; policies; energy resources; technology costs; environmental impacts; and infrastructure.

**Energy-Economic Market Characterization**
Analyze benefits and impacts of programs, portfolios, and policy options

**System**
Analyze system performance and technology interfaces in the context of the overall system

**Technology/Component**
Analyze technology and component performance, cost, and other attributes

**Resource**
Assess resource availability and characteristics
Estimated Technology Cost

Source: NREL, 2009
Comparing Technology System Results

• Technology models often make very different assumptions around key drivers such as:
  - technology cost
  - technology performance
  - resource data

• Challenge for modelers in reconciling these underlying assumptions as outputs roll up into integrated and system models skewing results
Comparing Energy Economic Analysis Results

2025 Renewable Capacity - 20% Penetration

"Standard Inputs"

2025 Renewable Capacity - 20% Penetration

"Aligned Inputs"
Regional Energy Deployment System (ReEDS) Model

- Integrating model of the 20% Wind Energy by 2030 Study.
- Multi-regional, multi-time period model of generation capacity and transmission infrastructure expansion in the U.S. through 2050.
- Extensive GIS databases used to account for geographic diversity of renewable energy technologies.

- Linear program
- Sixteen time slices in each year: 4 daily and 4 seasons
- 5 levels of geographic regions
- Existing and new transmission lines
- Stochastic treatment of wind resource variability – planning reserves, operating reserves, surplus wind
ReEDS Regions

- 3 Interconnects
- 13 National Electric Reliability Corporation (NERC) subregions
- 32 Regional Transmission Operators (RTOs)
- 134 balancing areas
- 356 resource regions
ReEDS Structure

Region Definitions
Time-slice Definitions

Transmission Data
Resource Data
Initial Capacity
Load Growth Forecast
Technology Cost/Performance Forecasts
Fuel Price Forecasts
State/Federal Rules/Incentives
Financing Assumptions
System Requirements

Load Requirements
Installed Capacity
Fuel Prices
Technology Cost/Performance Data
Wind Variability Parameters

Transmission Requirements

ReEDS Optimization

New Generating Capacity
New Transmission Capacity
Dispatch

min \( C_{gen \cdot cap} \cdot gen + C_{c \cdot cap} \)

s.t. \( gen > load \)

\( cap > peak \text{ load} \cdot (1 + \text{res marg}) \)

\( oper \text{ res} > res \text{ reqt} \)

\( gen + oper \text{ res} < cap \)

Electricity Price
Fuel Usage
RE Resources in ReEDS

WIND

CSP

GEO

BIO
2030 - Between PCA Transfers and In-PCA Use for Wind (All Classes)

Total Between PCA Transfer >= 100 MW (all power classes, onshore and offshore)
Arrows originate and terminate at the centroid of the PCA for visualization purposes; they do not represent physical locations of transmission lines.

Wind (MW) on Transmission Lines

Existing  New

100 - 200
200 - 500
500 - 1000
> 1000

Wind (MW) Used Inside the PCA

- 100 - 300
- 300 - 500
- 500 - 1000
- 1000 - 5000
- > 5000

Wind_Vision_06-19-2007 - DRAFT
Plug-in Hybrid Electric Vehicle Modeling

“The Grid”

Loads

Reserve Margins

Ancillary Services

Off-peak Reserves as needed
PHEVs* Can Increase Wind Penetration

* Assumes 50% PHEV-V2G penetration by 2050
Why this is Important

• Are we making reasonable forecasts with our current models – particularly around energy options and impacts?

• Do our climate models accurately reflect these options?

• Very important decisions and future pathways are being built upon our answers…
Various studies point to different pathways for reducing U.S. GHG emissions – EE and RE are critical in each.

Source: Emissions projections from EPA’s ADAGE model reference case based on EIA’s AEO 09; Waxman goals from Congressman Markey’s website; Other analyses from Union of Concerned Scientists, IEA’s Energy Technology Perspectives, Forthcoming NREL analysis conducted by EERE with McKinsey using 2008 DOE technology performance projections, Forthcoming NREL analysis conducted using 2008 EERE technology performance projections.
Electricity Generation Transitions under Blueprint

Source: UCS 2009
US Total Energy in 2030: Blueprint Scenario

Total Energy Blueprint Scenario, 2030

- Petroleum: 37%
- Gas: 20%
- Coal: 6%
- Nuclear: 11%
- Renewables: 21%
- Hydro: 4%
- Others: 1%

Total Energy: 77 quads

Source: UCS 2009
2030 Electricity Generation under CO2 Policies, UCS, 2009

Electricity Generation 2030

- Renewables: 29%
- Nuclear: 24%
- Combined Heat and Power: 16%
- Gas: 10%
- Coal: 10%
- Hydro: 10%
- Others: 1%

Total: 544 BkWhr
Alternative Futures

Source: NREL Analysis
Market Drivers

Annual Electric Generating Capacity Additions

- Coal
- Natural Gas
- Nuclear

Gas declines, PIFUA prohibits
Gas increases (50+ GW added in 2002)
PIFUA changed PURPA
CC efficiency
Low price through deregulation

Coal declines
CAAA deregulation

Nuclear emerges
Technology Available
Too cheap to meter

Nuclear decline
Interest rates
3-Mile Island (1979)
Chernobyl (1986)
Regulation
Carbon allowance price trends...

Carbon Allowance Price

[Graph showing carbon allowance price trends with different scenarios labeled: Carbon Cap, No CCS, No Southern Offshore Wind.]

Carbon Prices across Scenarios

[Graph showing carbon prices across scenarios with various models and the 167 GtCO₂-e milestone.]
Key Challenges

• Identifying, quantifying, and reducing uncertainties, including:
  - improving characterization of current technologies
  - understanding technology pathways and evolution
  - increasing our representation of market dynamics
  - accurately costing externalities

• Stochastic versus deterministic projections and adequately addressing risk

• Fully understanding sustainability issues and related constraints
Key Challenges

Emission reduction pathways may take many forms and can be framed around different strategies...

Sector-specific options
Technology development and deployment success
Economic restructuring
Societal changes
Behavioral impacts

Sharing global CO2 emission reductions among one billion high emitters
Shoibal Chakravartya, Ananth Chikkaturb, Heleen de Coninckc, Stephen Pacalaa, Robert Socolowa, and Massimo Tavonia
PNAS, May 19, 2009

Source: Historical and projected emissions data obtained from EPA’s AEO 09 Baseline
Social Issues…

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An Integrated Approach is Required

Social Capital

Networks