January 19, 2011

HOW TO DEVELOP CLEAN ENERGY SYSTEMS

Strategic systems development

Strategic: Decisions are based on the goal
Systems: Cost & performance is determined
by the whole system

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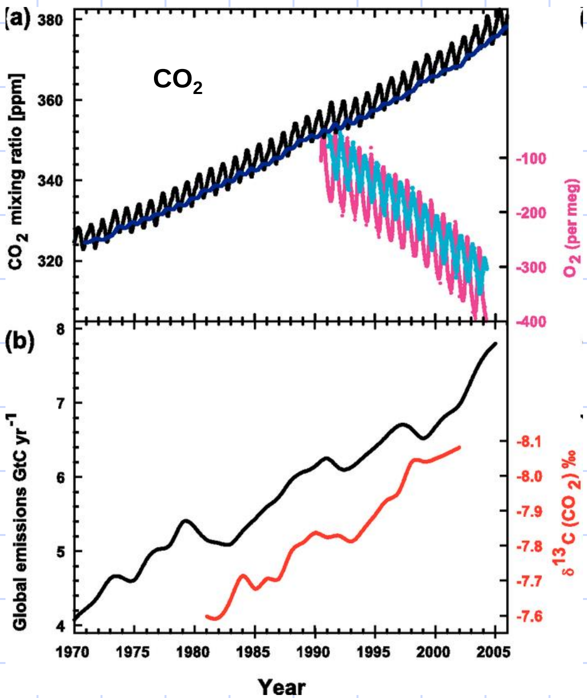
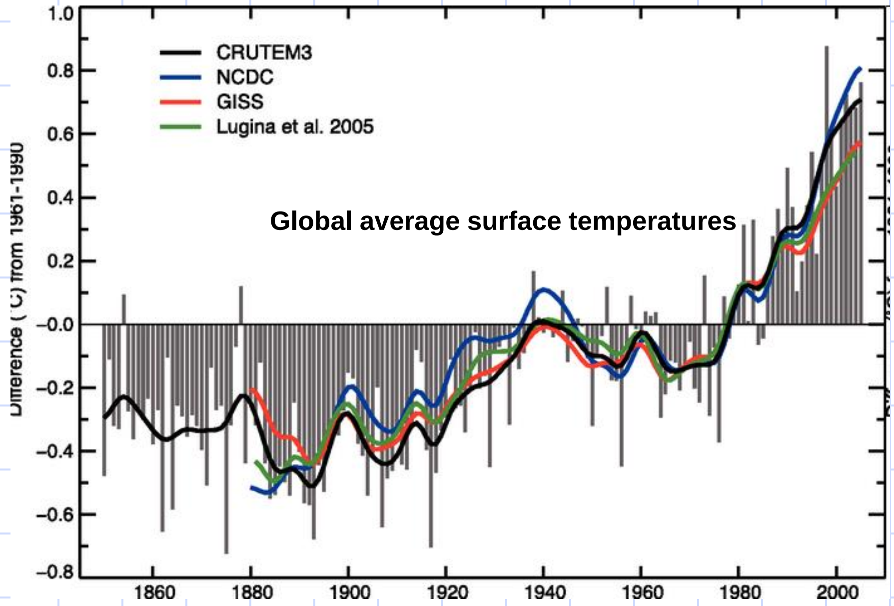
THE PROBLEM



Data from IPCC *Climate Change 2007* Working group 1, Chapter 2

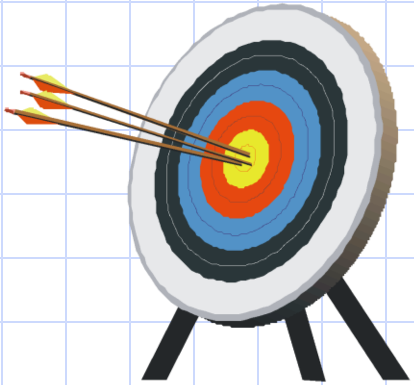


- The planet is warming ~ 1°C over the past century
- Burning fossil fuel is increasing atmospheric CO_2; a CO_2 induced temperature rise would be scary because CO_2 stays in the atmosphere for a long time
- While this could be random, correlation with industrialization suggests an anthropogenic hypothesis - caused by man
  - Mechanisms include deforestation, heat islands, atmospheric particulates, greenhouse gasses including CO_2
- The science is not settled
  - Random hypothesis has not been falsified
  - Causality relies on climate models
  - Most important mechanisms are unclear

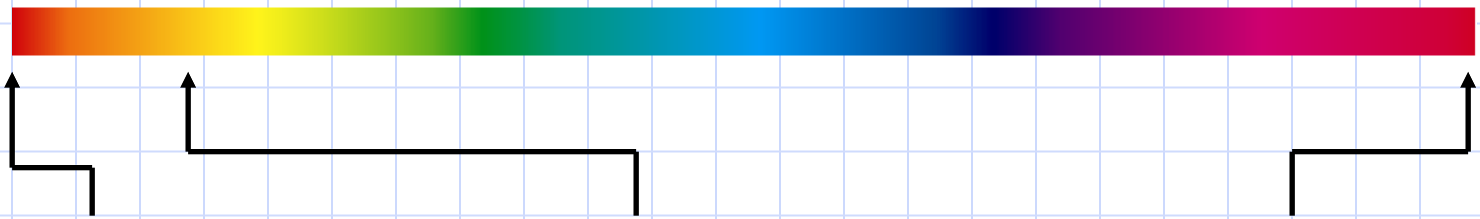
STRATEGIC GOAL

To reduce CO_2 emissions to 83% below 2005 levels by 2050 (President Obama 2009)

- Obama's goal is a good end state definition
  - Performance goal not a mandated solution
  - Judgment call based on science and risk
- Purpose
  - All decisions and interim goals are based on the strategic goal
  - Do not deploy systems that obstruct that goal
- Judgment factors:
  - Big reductions, 20% is not enough
  - Next generation migration time frame minimizes costs
  - Emission reduction involves less risk than adaptation, geo-engineering strategies
  - Reducing fossil fuel consumption is also justified on the basis of
    - Environmental impact
    - Finite resources, increasing cost
    - National security, health



SYSTEMS DEVELOPMENT APPROACHES



Evolution

- No goal
- Decisions based on
  - Natural selection
  - Physical principle
- Nature
- Artificial life
- Self organizing systems

Agile development

- Fuzzy goal (consumer products)
- Decision based on market feedback
- Advantage
  - ❖ Immediate returns
  - ❖ Quick, easy way to manage complexity, rapidly changing environment, ill defined requirements
- Disadvantage
  - ❖ Inefficient, ugly, expensive systems (think Windows)
  - ❖ **Big mistakes**, dead ends, extinction
  - ❖ Never achieves a goal

Rational planning

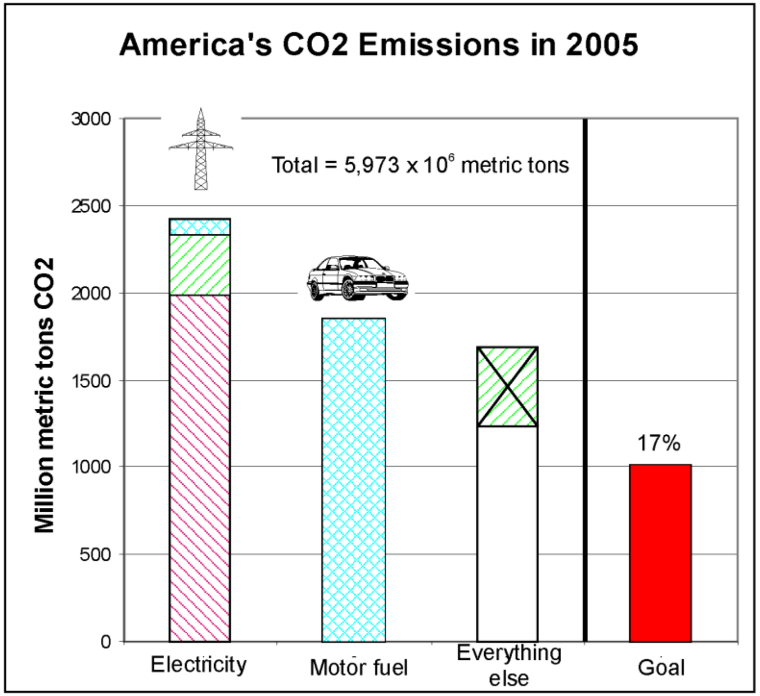
- Clear end state (strategic goal)
- Decisions are based on goal
  - ❖ Whole system focus, not components
- Advantage
  - ❖ Efficient, optimized systems
  - ❖ Structured client interaction simplifies the politics.
- Disadvantage
  - ❖ Planning takes discipline
  - ❖ An integrator needs to coordinate, enforce good process and best practices

EVOLUTION vs STRATEGY - EXAMPLE

- National Research Council published *America's Energy Future (AEF)* in 2009
  - Authored by members of the National Academy of Sciences and National Academy of Engineering
- The *AEF* was tasked to develop an evolutionary scenario based on "a projection of current economic, technology ... and policy parameters"
  - The *AEF* evolutionary scenario mixes legacy systems, changing technology and current policy resulting in confusion
  - No strategic goal
- The *AEF* conclusion:
  - There is no "silver bullet"
  - We need a "balanced portfolio," there are many ways to reduce CO_2 emission today, some enduring, some not
  - Nuclear is viewed as unattractive (because it is discouraged by current policy)
- A strategic analysis leads to a different conclusion
  - Very few feasible choices
  - Reveals some concepts to conflict with the goal

Strategy vs. Evolution, *American Scientist* 98:6, Nov - Dec 2010, p. 448

HIGH LEVEL ALLOCATION



- Reduce emissions to 83% of 2005 levels by 2050
- 2005 actual CO_2 emissions data published by EIA.
  - Bars show partial decomposition to fuel type:
    - Coal – red hash
    - Oil – blue cross hash
    - Natural gas – green hash
  - "Everything else" includes applications like space heating and difficult to replace usage like jet fuel.
- 2050 goal, red bar, is 17% of 2005 emissions.

Allocation

- Zero carbon electric grid
- Zero carbon motor vehicle fuel

STRATEGIC SCENARIOS

- Simple concept models of end state system configurations
  - Based on known technology
  - Ignore current policy and legacy system constraints (policy comes later)
  - Includes data based learning curves for performance/cost improvements.

- Analyze and compare system CO_2 and cost in sufficient depth to capture the structural essence - but no more.

- Strategic scenarios provide a clear definition of the technical feasibility of various choices.

- Strategic scenarios are followed by design reviews, then management decision milestones, then policy.

ZERO CO_2 SCENARIOS

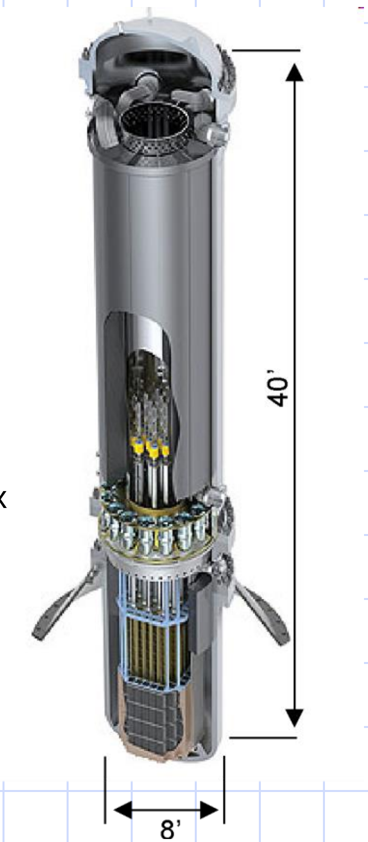
- Electric power
  - Natural gas baseline
  - Nuclear
  - Smart grid
  - Wind
  - Coal
  - Solar PV
  - Concentrated solar thermal
  - Geothermal
  - Stationary fuel cells
  - Tides
  - Ocean thermal gradient
  - Storage
  - Hydro
- Motor vehicle fuels

NUCLEAR SCENARIOS

- 1 - Next generation site-built reactors
  - With national commitment France took 40 years to build a grid that is 80% nuclear
  - Technically feasible zero carbon primary power
  - Direct cost is competitive
  - Risk: migrating to 100% will require innovation

Coal = 6.2 ¢/kWhr
N Gas = 6.5
Nuclear =6.6
Direct cost of new generation with <u>same cost of capital</u> (*The Future of Nuclear Power*, MIT, 2009, p. 6

- 2 - Modular reactors
  - Lower cost, factory built, truck transportable
  - Many variations
  - Smaller size lower risk, insurable
  - Cost comparisons & constraints unclear



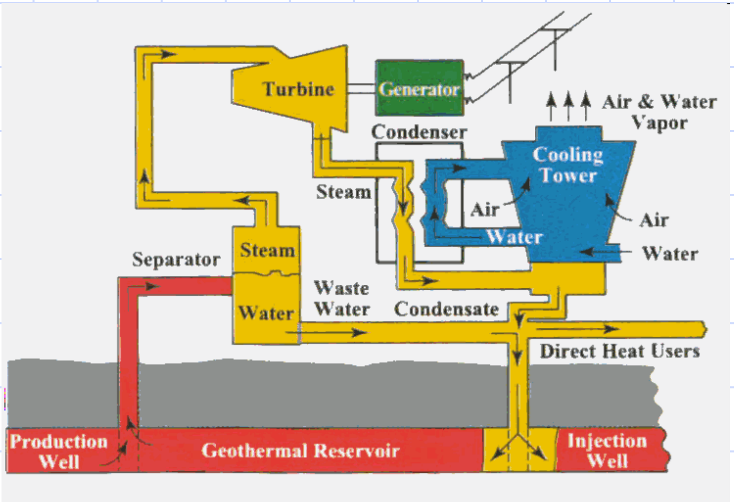
Babcock & Wilcox
125 mW module

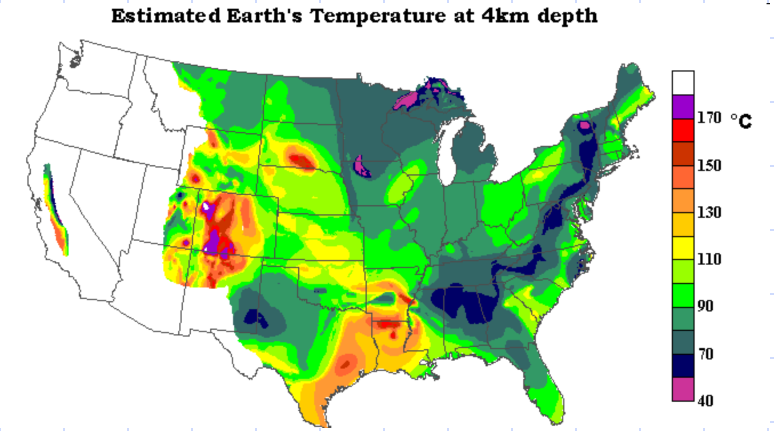
- 3 - Breeder reactors (long term scenario)
  - Reprocessed fuel, less primary consumption, less waste
  - Essentially sustainable, uranium from seawater

- Blue Ribbon Commission dealing with current issues
  - Institutional structure
  - Fuel cycle options
  - Transport and storage
  - Safety and proliferation

GEOTHERMAL SCENARIO

- Advantages
  - Base load
  - Zero carbon
  - Secure
  - Compact
  - Distributed
  - Cheap at high grade sites
- Risk areas
  - Geographic limits
    - Costs at lower grade sites
  - Water
  - Induced seismic
- Potential
  - 100 GW by 2050*
    - Hydro today 78 GW**





* The Future of Geothermal Energy, MIT, 2006
** DOE/EIA nameplate

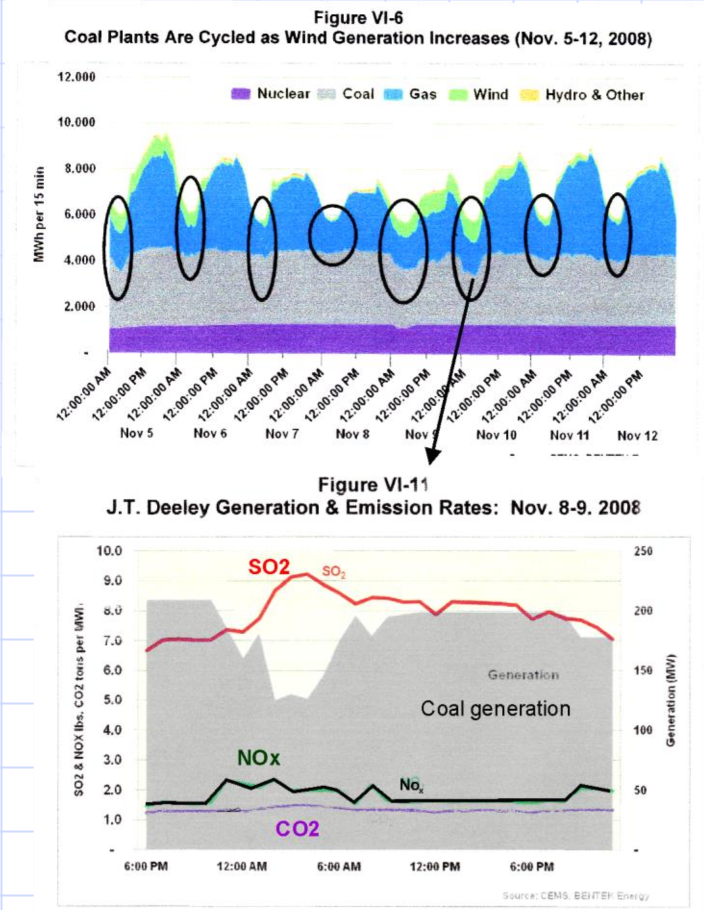
WIND SCENARIOS

- Advocate's end state: 30% wind, 70% natural gas
  - Not a strategic solution, cannot achieve zero carbon
  - Risk: Discard wind to achieve zero carbon
  - Risk: No system level emission validation
    - 5% wind penetration causes coal plants to cycle increasing SO_2 & NO_x emissions, real CO_2 emission reduction unclear.
  - Risk: Obstructs commitment to strategic solutions

- Niche - Wind/hydro dispatchable subsystems
  - Denmark wind with Norway fjord pumped hydro works
  - Pacific Northwest
  - Need system integration

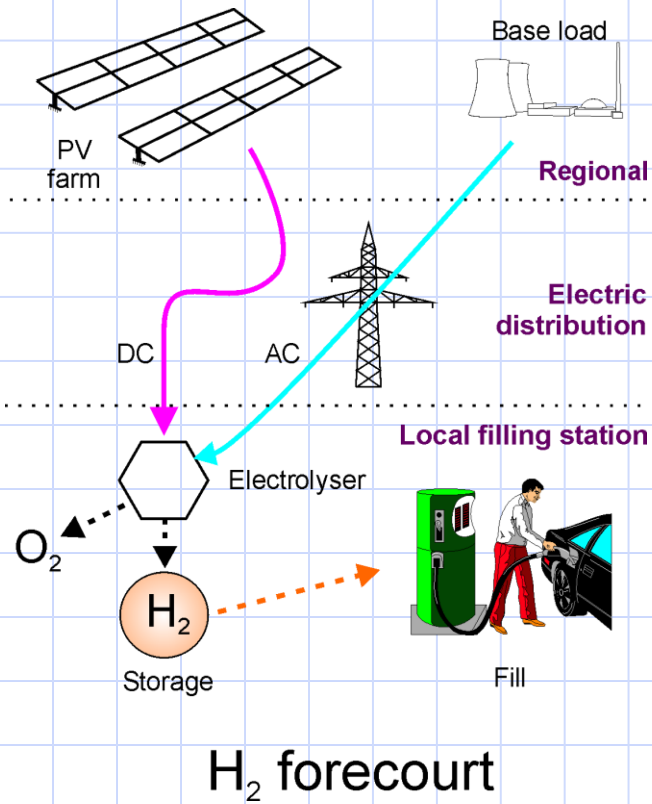
- Niche – Wind/geothermal dispatchable subsystems

- Niche - Intermittent tolerant applications
  - Water desalinization
  - Hot water heating



MOTOR VEHICLE FUEL SCENARIOS

- Internal combustion engines
  - Synthetic fuels
  - Bio fuels (feedstock?)
  - Other?
- Electrochemical cells
  - Closed cells (batteries)
  - Open cells (fuel cells)
- Characterize delivery systems
- The optimum zero carbon solution is not obvious.



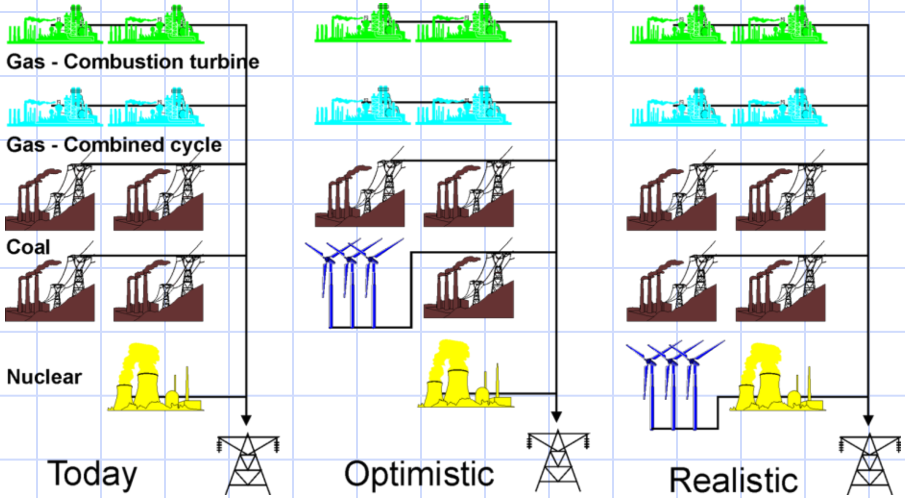
DEVELOP THE WHOLE SYSTEM

- Development should be driven by strategic system requirements
  - Clean components do not mean clean systems - Wind
    - Every wind kWh must be backed up with 3-4 kWh from dispatchable fossil fuel generators
  - Wind farms cause coal plants to cycle increasing emission of SO_2 and NO_x above no wind emissions (Bentek)
  - System CO_2 emissions are less than expected

- Power systems capability has atrophied since deregulation
  - Fragmented management, no integrator, many agencies are responsible for pieces of the system
    - Basic tasks like balancing are a struggle
  - No empirical system studies
  - Wind integration teams focus on electromechanical integration ignoring emission and cost

- System cost – Wind
  - Wind save fuel and competes with the wholesale cost of fuel

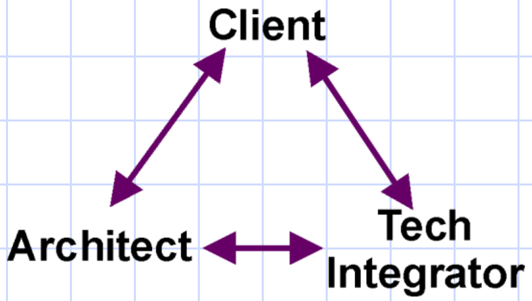
- Needs
  - System requirements
  - Integrated management structure
  - Empirical system analysis



AN ARCHITECTURE PROBLEM

"We don't need a system integrator, the markets will do it."

nonsense



GOVERNANCE MODEL

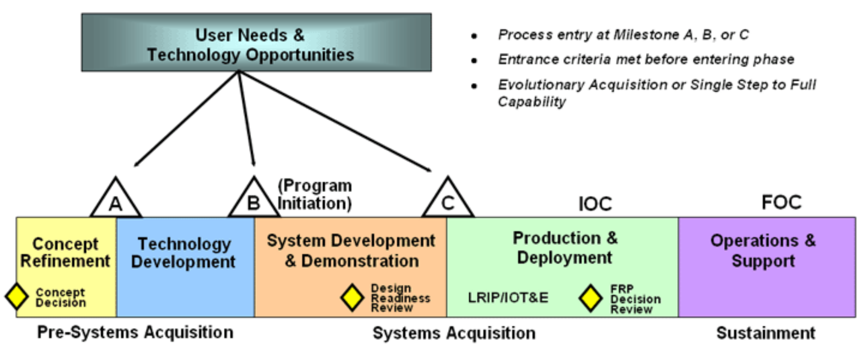
- Roles are separate and distinct
- No one role dominates
- Healthy tension between roles

- Architect – President Obama
  - Articulates goals
  - Responsible for finding a solution (any solution)
  - High level coordination
  - Proposes policy options
- Tech Integrator – DOE
  - Responsible for technical analysis, research & development, technical coordination
  - Maintains a system development plan
    - Phases
    - Design reviews, management decision milestones
  - Enforces good process, best practices
- Client – Congress
  - Congress represents general public, special interest groups
  - Responsible for value judgment
  - Chooses policy

MANAGING TECHNOLOGY CHANGE

"Why bother planning when everything is going to change."
nonsense

- Technology change is anticipated and managed as risk using phased development
- Engineering development plans consist of a sequence of phases separated by design reviews and management decision milestones
- Design reviews are a critical independent evaluation of fact
- Management decision milestones are value decisions
- Systems are decomposed into a nested set of many such plans with interrelationships and dependencies
- Systems integrator enforces discipline and provides development coordination



DODI 5000.2

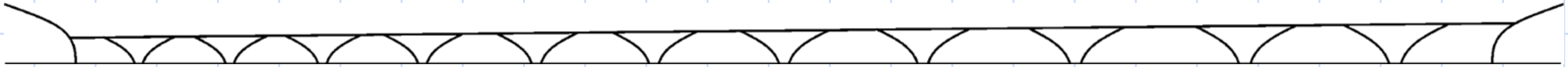
SO MANY STAKEHOLDERS!

- One challenge is the number, diversity and innumeracy of stakeholders.
  - Energy affects everyone and everyone has an opinion.
- The interface between the customer and the contractor is always troublesome
  - Energy systems stakeholders are far more complex.
- Informed stakeholders simplify the politics. We need to experiment with novel open methods for engaging stakeholders in design reviews and management decisions.
  - Mechanisms to mitigate bias, push back against lobbyists and special interests
  - Large public works projects provides guidance.
  - Wilson bridge example

PUBLIC WORKS GUIDANCE

- Like energy systems, large public works projects involve consensus decision making by many diverse stakeholders

- The new Woodrow Wilson bridge (I95 across the Potomac)
  - Engineers explored the full range of options: tunnels, high bridge, draw bridge (1 year), then
  - Value choice made through extensive interface with the public (local town hall meetings, briefings with local, state and federal politicians (3 years)



Woodrow Wilson Bridge

- Lesson for clean energy systems
  - The hard part is building a public consensus
  - Consensus building is simplified by clear and simple choices
    - Separate technology from value choices
    - Strategic scenarios
    - Open design reviews

OPEN DESIGN REVIEWS

- Purpose
  - Does the system satisfy requirements?
  - Clarify issues and problems to be resolved
  - Provides the factual basis for value choices
- Format
  - Public presentations to professionals
  - Cross examination of experts by their peers
- Agenda
  - State requirements/goals
  - Compare the system with requirements
    - Establish a working group plus senior advisors
    - Consolidate scenario results into a written report
    - Public hearing (webinar) to find fact
    - Publish comparisons on the web seeking feedback
    - Upgrade analysis based on feedback.
  - Document technical results (Minority/majority technical opinions)
- Followed by client value choice (proceed, redirect, pause and re-evaluate, terminate)

THE REALLY BIG MISTAKES

- An Eberhardt Richten maxim is that the really big mistakes are made on the first day
  - Can’t reposition the house after the foundation is poured
- Big mistakes in energy
  - Corn based ethanol
    - Increases food prices
    - Generates more CO_2 than no mandate
  - Renewable portfolio standards
    - Dispatchable renewables are excellent
    - Intermittent renewables conflict with energy-on-demand systems
- It is too soon for a comprehensive energy bill
  - Clean energy can be stimulated by increasing the cost of carbon fuels or decreasing the cost of clean sources
  - We need a competent plan and a compelling vision

CONCLUSIONS

- Strategic development
  - The strategic goal drives decision-making
  - Avoids dead end system concepts
  - Very few feasible strategic solutions
- Systems not components
  - Performance metric is system emissions and cost
  - Intermittent generators (wind, solar) are incompatible with zero emissions and power-on-demand systems
- Where is the system integrator?
  - Coordinate development
  - Enforce good process and best practices
    - Keep technology and policy separate
    - Phased development, open design reviews
- Global leadership
  - Coordinate international development
  - Support for emerging economies
  - We do not yet have a strategic plan or a clear and compelling vision

Strategic vision

CHANGING TECHNOLOGY RISK

"Why bother planning when all the technology is going to change?"
nonsense

- Internet lessons
  - IT disruptions were market based entrepreneurial innovations, killer apps
    - Enabled by predictable, rapidly improving hardware
  - Unlike IT, energy systems hardware technology and physical constraints are mature
    - Since 1890, the really big innovation was nuclear fusion as a heat source
    - No new alternate generation concepts since the 1970's
    - Batteries are likely to see 10% not 10x improvements
  - Search for novel systems concepts (integrated wind/hydro, ice air conditioners)

- Most technology change can be anticipated and managed as development risk
  - Examples: small modular nuclear reactors, hydrogen fuel cells
  - Major weapon systems have 40 year life cycle and 20 year development.
  - Engineers manage this risk with disciplined phased development

- True technology disruptions (fusion, zero point energy) would change the plan

MANAGEMENT REVIEW

- Purpose:
  - Choose the best balance of cost, performance, schedule and risk.
  - Develop policy recommendations.

- Tasks
  - Develop protocols and procedures after consultation with planning experts and public works communities of practice.
  - Will likely consist of many presentations, Town Hall meetings and public hearings.

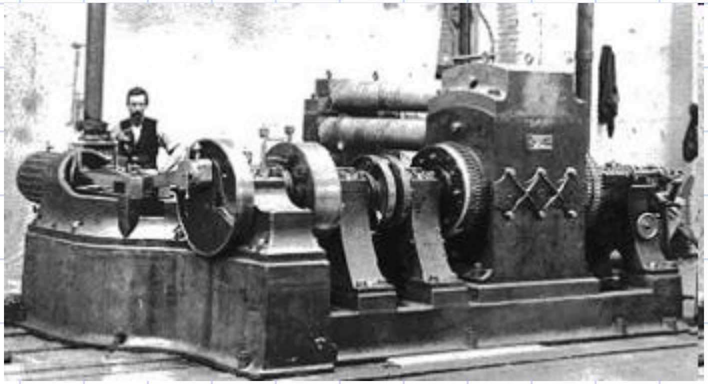
GLOBAL LEADERSHIP

- The big problem with global CO_2 emission is emerging economies.

- Need a global solution that is cheap, safe and secure.
  - What is the cost potential of Small and Modular nuclear power Reactors?

ELECTRIC POWER SYSTEMS HISTORY

- 1890-1970 Electrification build-out and reliability.

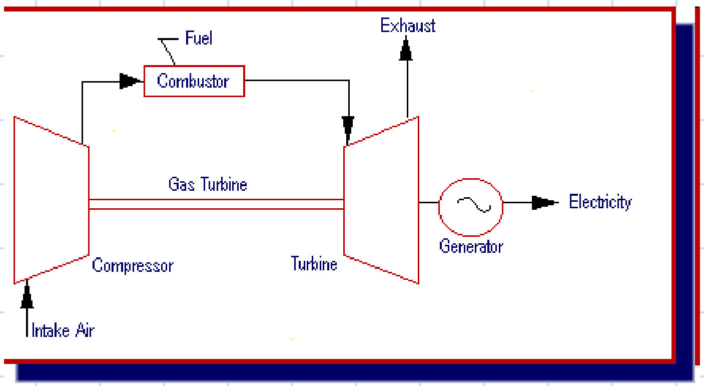


Edison Pearl Street power station

- 1970-today Cost reduction through deregulation
  - Divide system into competitive (generation) and monopolistic (transmission & distribution) functions.
  - Consequence of deregulation is loss of systems engineering capability.
  - California-Enron debacle, ISO vs wind advocates

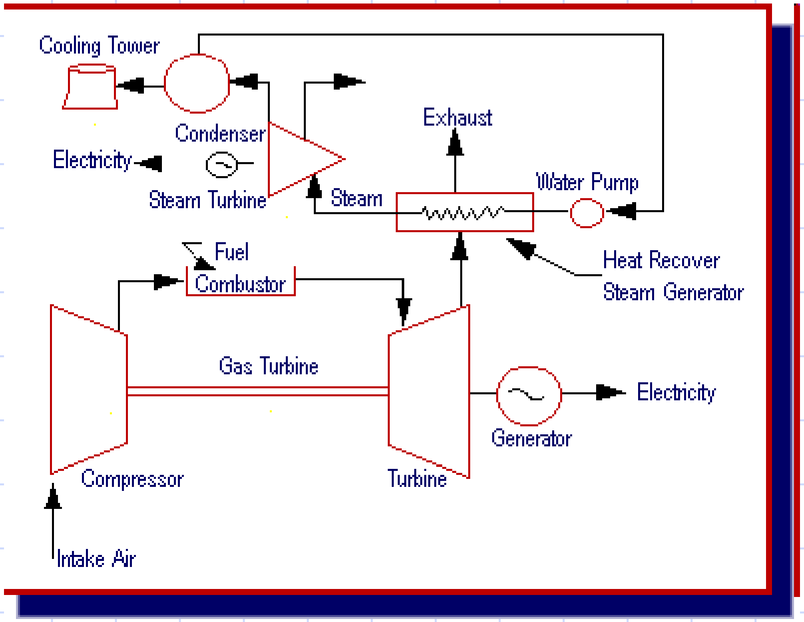
- 2009 Clean (but also cheap and reliable)

NATURAL GAS TODAY



Gas - Combustion turbine C-GT

□ = 37%

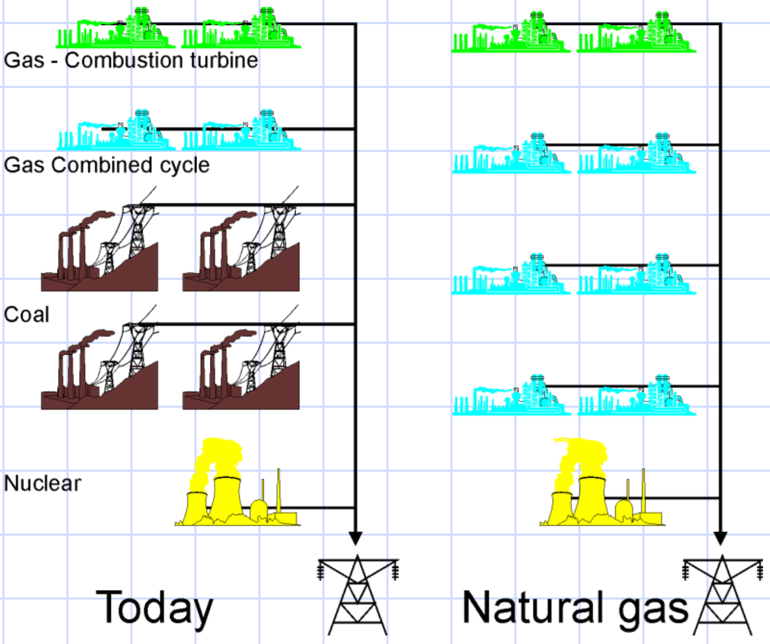


Gas - Combined Cycle G-CC

□ = 51%

NATURAL GAS SCENARIO

- Interim solution
- Cost/performance of shifting all fossil generation to advanced gen natural gas
  - Combustion turbine □ = 37%
  - Combined cycle □ = 51%
- Useful reference for evaluating other scenarios



NUCLEAR POWER TODAY

- Nuclear power is zero carbon & feasible
  - During the past 40 years, the French built a power system that is 78% carbon free
  - During the next 40 years the US can certainly do the same thing by just copying the French (though surely we could do better)

- Direct cost is competitive
  - Nuclear appears expensive because of high cost of capital
    - Policy could sweep away this barrier
  - Small modular reactors offer promise

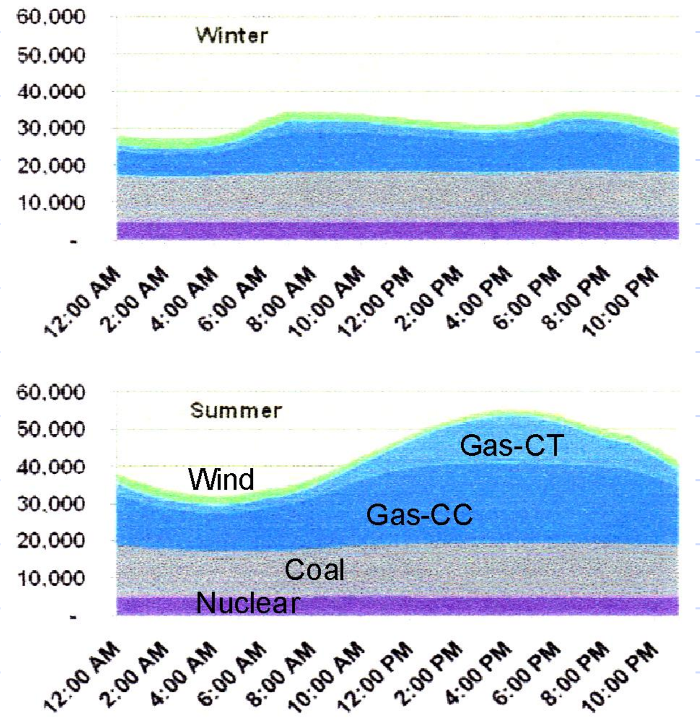
- Presidents Blue Ribbon Panel on America's Nuclear Power Future – new plan
  - Review policies, recommendations
  - Fuel cycles & reactor technologies
  - Waste transport & storage
  - Institutional options
  - Trust

Coal = 6.2 ¢/kWhr
N Gas = 6.5
Nuclear =6.6
Direct cost of new generation with same cost of capital[1]

[1] *The Future of Nuclear Power*, MIT, 2009, p. 6

SMART GRID SCENARIOS

- Apply information technology to the grid?
- What is the purpose?
  - Reliability
  - Fault recovery
  - Load leveling
- What is the system concept?

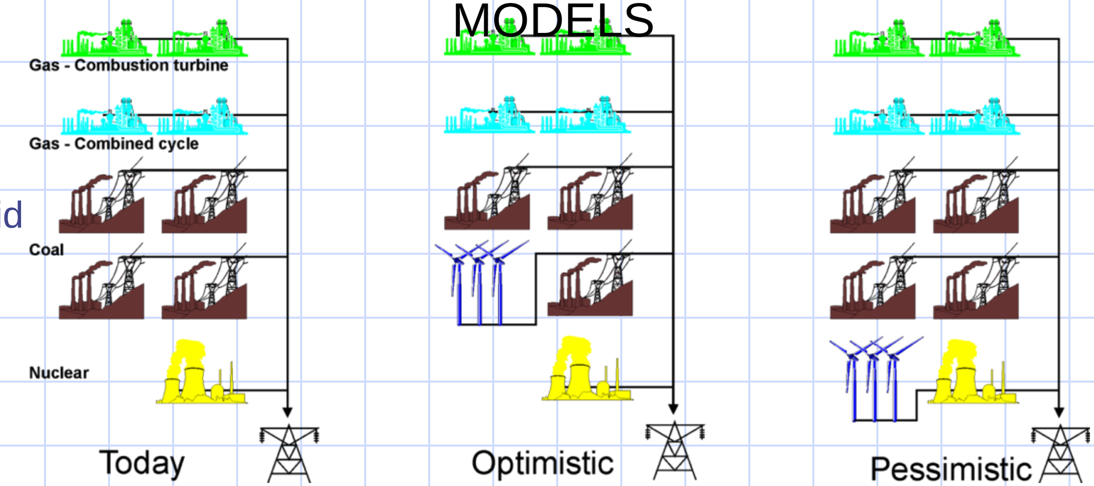


ERCOT 2009 Average hourly generation by fuel type and season (mW)

WIND POWER TODAY

- Current system concept consists of simply plugging wind farms into the grid
- Dedicated fossil fuel backup is required
  - Incompatible with zero carbon grid
  - What is the role of wind in a zero carbon grid?
- Firm capacity is unclear
  - Basis for pricing models
- No empirical evidence that wind reduces system emissions

SYSTEM MODELS



Optimistic:
- Firm capacity equals average capacity
- Wind competes with the wholesale price of electricity (Current pricing model)

Pessimistic:
- Firm capacity equals zero
- Wind competes with the wholesale price of fuel

PV SCENARIOS

- Grid connect
    - Emission limits
- Off the grid
- Integrated dispatchable subsystems
    - PV/hydro
- Intermittent tolerant applications
    - Storage
    - Hydrogen forecourt

STORAGE SCENARIOS

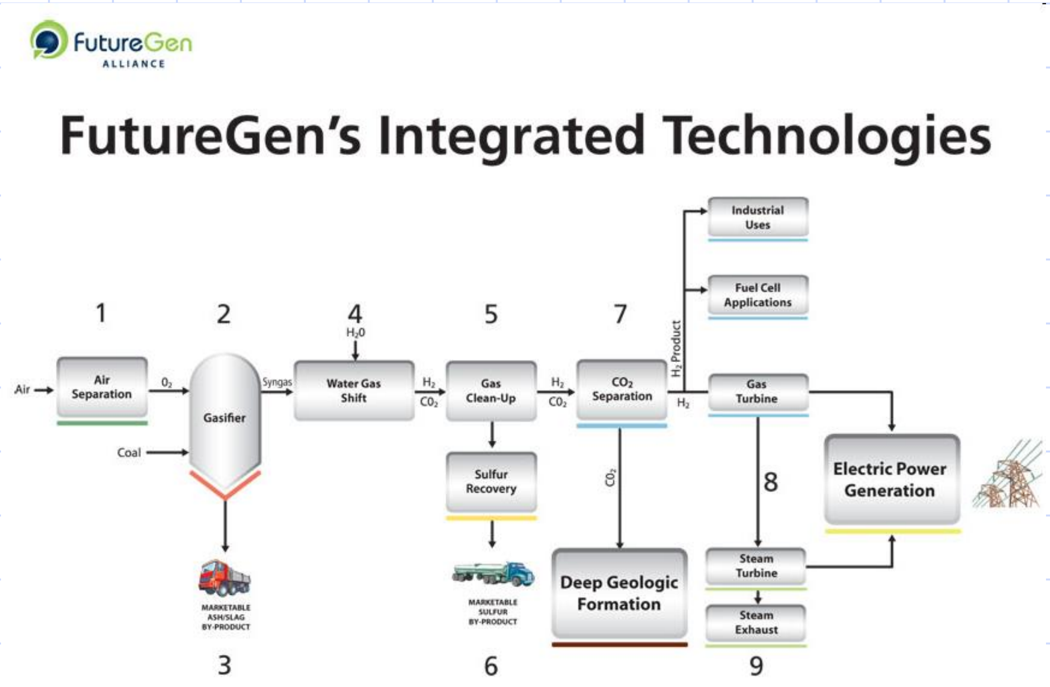
- Purpose – firm capacity
- Technologies
  - Flywheels
  - Capacitors
  - Superconducting magnets
  - Batteries
  - Pumped hydro
  - Compressed air
  - Thermal

Compressed air storage

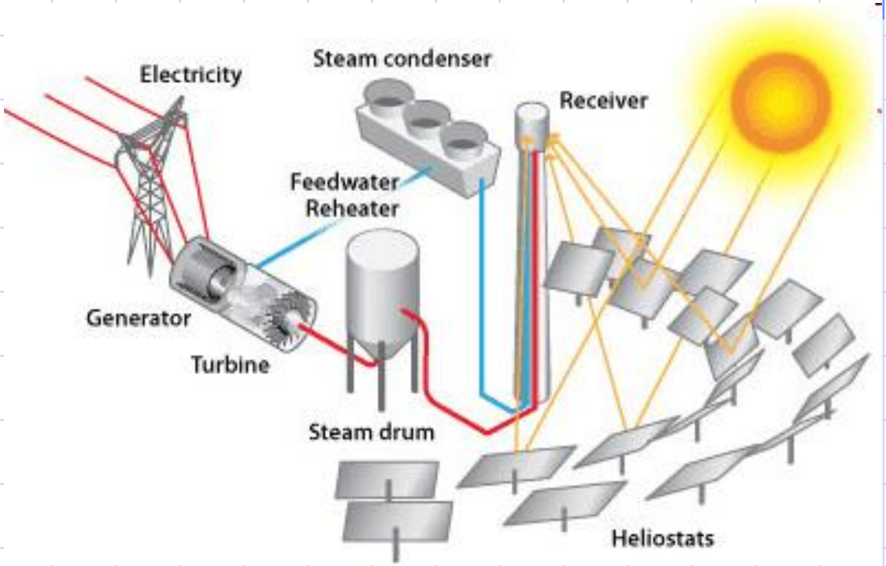
Denholm, P., et al., *Role of Energy Storage with Renewable Electricity Generation*, NREL/TP-6A2-47187, January 2010, Available at: http://www.eia.doe.gov/oiaf/aeo/assumption/pdf/electricity.pdf#page=3

COAL SCENARIOS

- Integrated gassification with carbon sequestration
  - Future Gen
- Novel carbon capture techniques
  - What is the likelyhood of major innovations



CONCENTRATING SOLAR SCENARIO



SUPPLY BASED GRID