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ENGINEERING CLEAN ENERGY SYSTEMS

- **Strategy vs evolution**
- Scenario development
- Management innovations
- A role for NASA

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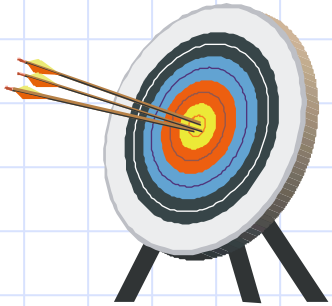
STRATEGIC GOALS

- Put a man on the moon in 10 years (... and safely return)
  - Kennedy's May 1961 Apollo goal



- An 83% reduction of CO_2 emissions below 2005 levels by 2050 (... using systems that are reliable and cheap)
  - Obama's 2009 Copenhagen goal
  - Good end state performance definition
    - Big CO_2 emission reduction in next generation time frame
    - Consistent with a sustainable post fossil fuel economy
  - It is premature to say that this goal is too expensive or unachievable

CLASSIC STRATEGIC PLANNING

1. Set the purpose
   - ❖ The strategic goal
   - ❖ The end state
2. Clarify alternative solutions, a factual analysis
   - ❖ Strategic scenario development
   - ❖ System tradeoffs
3. Choose a direction, a value judgments
   - ❖ Set specific goals
4. Develop plans to get there from here
   - ❖ Phased development, staged deployment
   - ❖ Interim milestones

IMPORTANCE OF A STRATEGIC GOAL

Spectrum of system design methods

Evolution

- No goal
- Decisions based on
  - Local optimization, rule
  - Natural selection
- Examples
  - Ecosystems
  - Artificial life
  - Self organizing systems

Agile development

- Fuzzy goal (consumer products)
- Decision based on market feedback
- Advantage
  - Easy way to manage ill defined and rapidly changing requirements
  - Quick, immediate returns
- Disadvantage
  - Confusion, Inefficient, ugly, expensive systems (think Windows)
  - **Big mistakes**, dead ends, extinction
  - May never achieve the final goal

Rational planning

- Clear end state (strategic goal)
- Decisions are based on goal
- Advantage
  - Focus resources
  - Avoid big mistakes
  - Elegant, optimized systems
  - Structured processes simplifies the politics.
- Disadvantage
  - An integrator needs to coordinate, enforce good process and best practice
  - Planning takes discipline

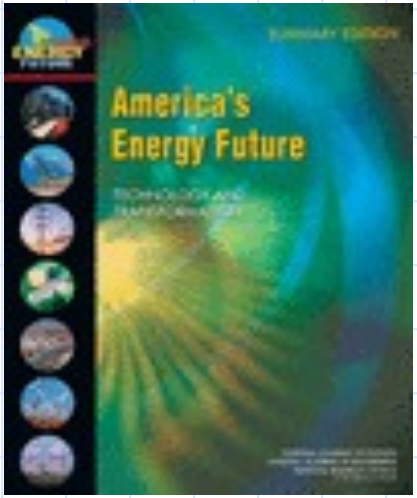
Pavlak, A., Strategy vs. Evolution, *American Scientist* 98:6, Nov - Dec 2010, p. 448

EVOLUTION vs STRATEGY - EXAMPLE

- National Research Council published *America's Energy Future (AEF)* in 2009

- 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
  - There is no "silver bullet," many ways to reduce emissions
  - 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
  - Fewer feasible choices
  - Reveals some concepts to conflict with the goal



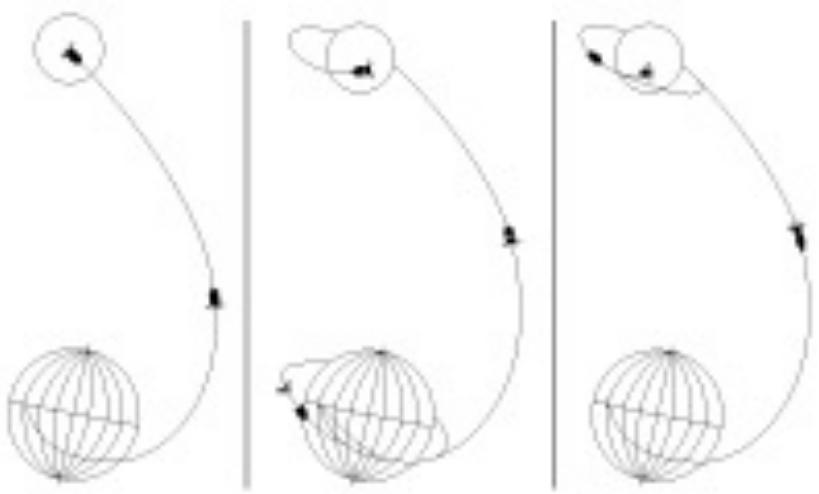
★ Evolution starts from where we are and attempts to move forward

★ Strategy starts from where we want to be, then develops a plan to get there from here

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

STRATEGIC SCENARIOS

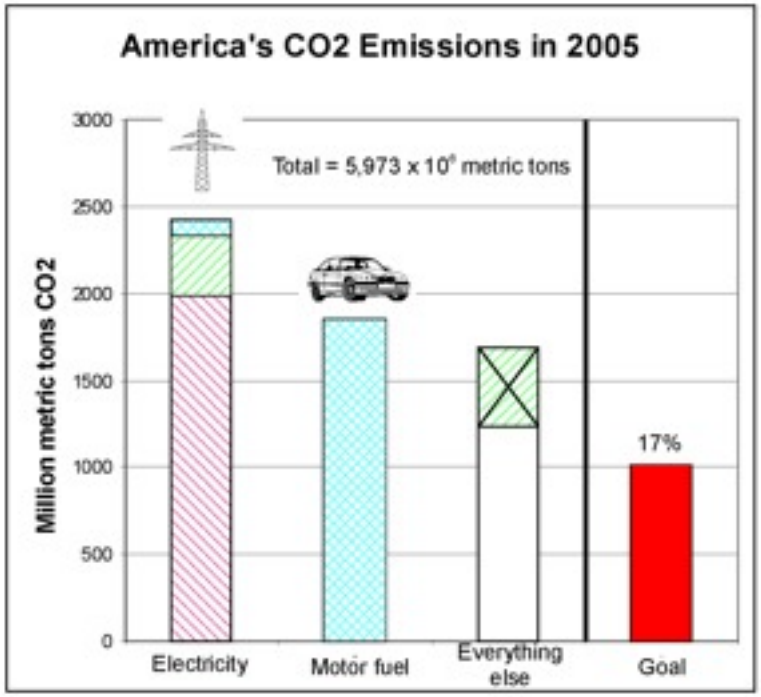
- Simple architectural models (components & interfaces) of end state system configurations
  - Start with a blank sheet of paper and known technology
  - Ignore current policy and legacy system constraints
    - Strategic scenarios are simpler than evolutionary scenarios
- Capture only enough detail to analyze and compare system cost/performance
- Provide a factual definition of the feasibility of various choices.
- Strategic scenarios are concluded by design reviews
- Strategic scenarios are followed by management decision milestones, policy, plans



Apollo scenarios

REQUIREMENTS DECOMPOSITION

An 83% reduction of CO_2 emissions below 2005 levels by 2050



Data source: DOE/EIA

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

- Actual 2005 emissions divided into three categories
  - Electric power generation
  - Motor vehicle fuel
  - Everything else, includes difficult substitution
- Fuel use designated by patterns
  - Coal - red hash
  - Oil - blue cross hash
  - Natural gas - green hash
- The 2050 goal (red bar) requires:
  - Zero carbon electric power system
  - Zero fossil fuel for motor vehicles

STRATEGIC ENERGY SCENARIOS

ELECTRIC POWER SCENARIOS

- Natural gas baseline
- Nuclear
- Wind
- Coal
- Solar PV
- Concentrated solar thermal
- Geothermal
- Stationary fuel cells
- Tides
- Ocean thermal gradient
- Hydro

ELECTRIC POWER COMPONENTS

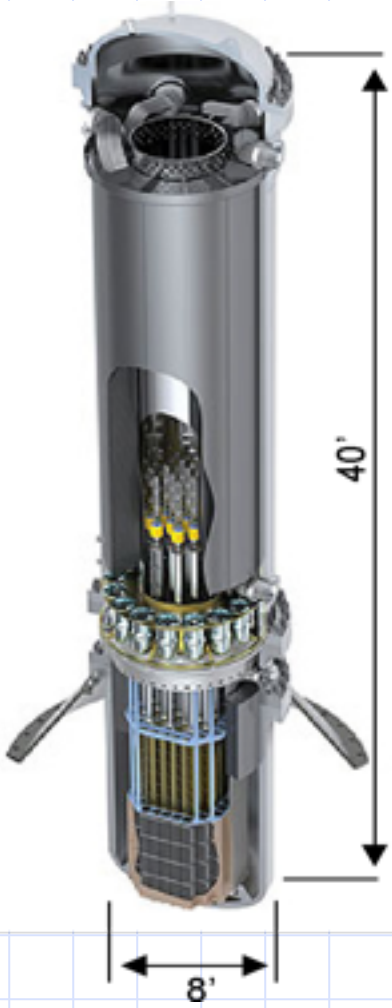
- Electric power system operations & markets
- Smart grid
- Storage

MOTOR VEHICLE FUELS

- Batteries
- Fuel cells
- Ultra capacitors
- Bio & synthetic fuels

NUCLEAR SCENARIOS

- Traditional LWR, French electric power system
  - 90% carbon free today (80% nuclear, 10% hydro)
  - Took 37 years
- Small modular reactors
  - Lower cost, factory built, truck transportable, many variations
- Liquid fluoride thorium reactor (LFTR)
  - Not fissile, load following, well suited to commercial power
- Molten salt reactor (Gen 4)
- Fast Breeder reactors
  - Reprocessed fuel, essentially sustainable
- Presidential Blue Ribbon Commission

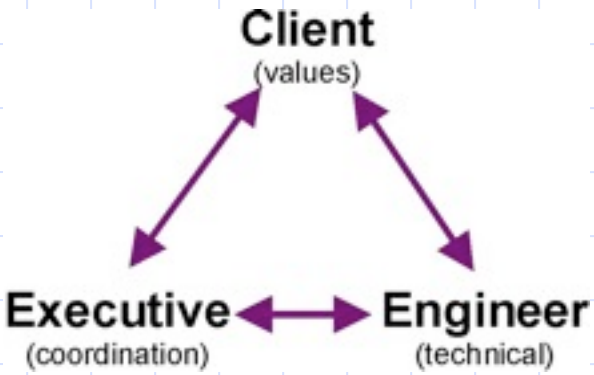


Babcock & Wilcox
125 mW module

WIND SCENARIOS

- On demand system requirement conflicts with intermittency
  - Intermittent generators cannot stand alone
    - Cannot deliver reliable power on demand by themselves
  - Increases net load fluctuations
    - Conflicts with level load
  - Plugging wind into the system prevents the system from reaching low carbon
- Partition the system into subsystems
  - Intermittent generator + something else
    - Each subsystem meets system requirements for reliable, cheap, clean
  - Alternative partitioning?
- Scenarios are concluded with system design reviews
  - Reliability
  - Cost
  - Emissions
- Wind + fossil fuel
  - Cannot achieve zero carbon, must discard wind to achieve zero carbon
  - No empirical system level emission validation
  - Obstructs commitment to base load solutions
- Wind + storage
  - Primary barrier is cost of seasonal/annual fluctuations
  - Water desalinization
  - Water pumping & irrigation
- Wind + hydro
  - Denmark wind with Norway fjord pumped hydro works to a degree
  - Pacific Northwest issues
- Wind + geothermal

ARCHITECTURE PROBLEM



GOVERNANCE MODEL

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

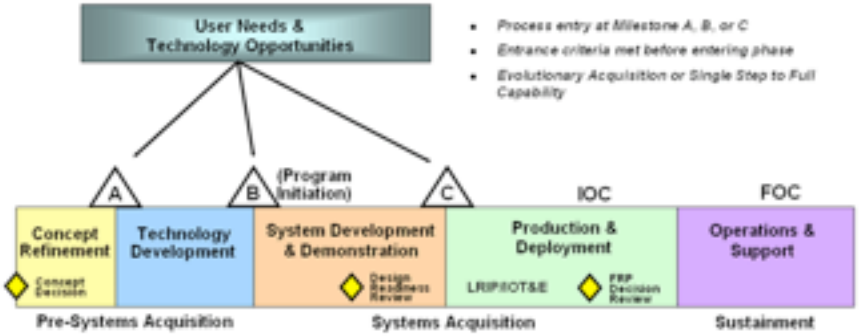
- Executive - President, State Governors
  - Articulate performance goals
  - System integrator
    - Coordination, integration, management structure
    - Enforces good process & best practices
    - Maintains system development plan with phases, design reviews, management decision milestones
  - Proposes policy options
- Engineer - National laboratories, various experts, laboratories, manufacturers
  - Responsible for R&D, technical analysis
- Client - Congress, State Legislatures
  - Represents general public, special interest groups
  - Responsible for value judgement
  - Chooses policy

Pavlak, A., Architecture Governance: Management Structure for Creating Architectrure, *Architecture and Governance 3:4,* November 2006, pp. 28,29.

MANAGING TECHNOLOGY CHANGE

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

- Technology change is managed as risk using phased development
- Engineering development plans consist of a sequence of phases
- Phases are 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
- Architect enforces discipline and provides development coordination



DODI 5000.2

DESIGN REVIEWS

- Purpose
  - Is progress consistent with requirements?
  - Clarify issues and problems to be resolved
  - Provides the factual basis for value choices
- Traditional format
  - Closed session, well defined client/contractor
  - Stating requirements, performance metrics
  - Developers present system progress and status
  - Cross examination by expert design review board
- An open format would encourage buy-in by multiple stakeholders
  - The number and diversity of stakeholders makes clean energy unique
  - Open format allows public to witness give and take, perhaps participate
  - Provides factual pushback against hype and spin
- Followed by client value choice (proceed, redirect, pause and re-evaluate, terminate)

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

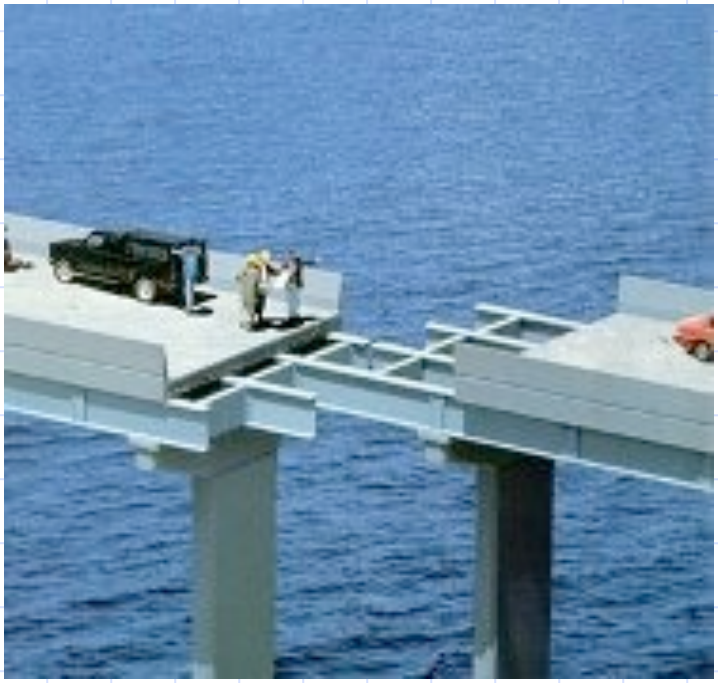
- The new Woodrow Wilson bridge (I95 across the Potomac)
  - Engineers explored the full range of options: tunnels, high bridge, draw bridge (1 year), then
  - Value choice made through extensive interface with the public (local town hall meetings, briefings with local, state and federal politicians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

THE REALLY BIG MISTAKES

- The really big mistakes are made on the first day (Eberhardt Richten)
  - Flash Gordon scenario
  - Expensive to reposition the house after the foundation is set
- Potential big mistakes in energy
  - Corn based ethanol
  - Renewable portfolio standards
  - Large scale wind
- Policy comes last
  - Clean energy can be stimulated by increasing the cost of carbon fuels or decreasing the cost of clean sources
  - First we need scenarios



CONCLUSION

- We have a good strategic goal
  - 83% CO_2 emission reduction below 2005 levels by 2050
  - Reliable, cheap, clean
- Strategic planning is the best management approach
  - Strategic goal drives decision making
  - Elegant systems, focus, avoid big mistakes
  - Next step - strategic scenarios
- Scenarios provide system level estimates of cost/ performance
  - Reliable, cheap, clean is a system requirement
  - Think integrated subsystems for intermittent generators
- Phased development and staged deployment manages technology change
- Open design review clarifies fact and builds public confidence by pushing back against hype

Strategic vision

A ROLE FOR NASA

- Power systems engineering capability has atrophied since 1970's deregulation
  - Monopoly power systems departments are gone
  - Highly fragmented regulatory structure
- Electric power needs a system integrator responsible for reliable, clean and cheap
  - Manage system scenario development
  - Enforce best practices (e.g. open design reviews)
  - Assess management structure for power systems operations
- NASA has a unique skill set
  - Systems engineering & development
  - Technology neutral, not a developer
- International leadership?