Engineering Clean Energy Systems

- Systems
- Strategy
- Concept definition phase
- Open critical reviews

Dr. Alex Pavlak
alex@pavlak.net

System Development Methods

Strategic planning

- Characteristics – Clear and stable goal
  - Start with a purpose, a vision of where you want to be
  - Choose a direction
  - Develop a plan to get there
  - Waterfall development
- Advantages
  - Goal provides priority
    - **Focus on what's important**
  - Don't do things that block the goal
  - Efficient systems
- Disadvantage
  - Big mistakes from changing goals
- Example – mature systems, high reliability

Agile development

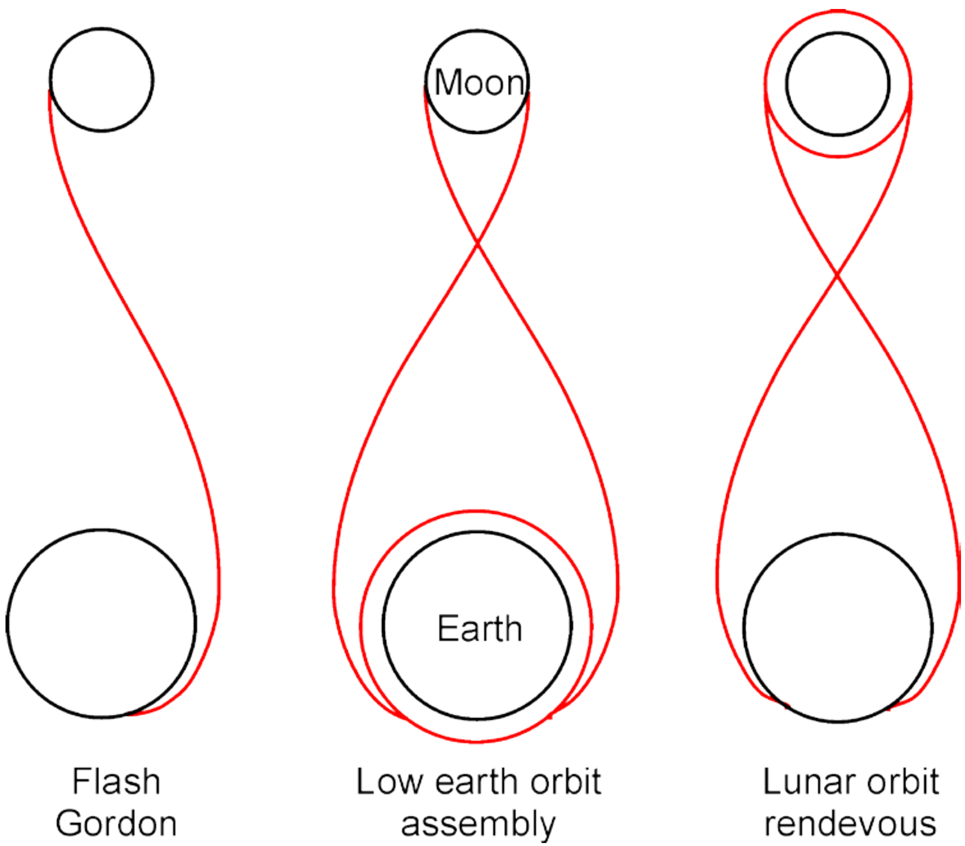
- Characteristics – Fuzzy goal
  - Iteration
  - Local optimization
    - Natural evolution
  - Rapid prototyping
  - Spiral development
  - Requires an inexpensive cycle
- Advantages
  - Adapts to changing requirements
  - Clarifies fuzzy goals
- Disadvantage
  - Dead ends, stranded technology
- Example – Early internet, consumer products

Pavlak, A.,
Strategy vs. Evolution,
American Scientist, 98, 2010,
pp. 448-450

Dr. Alex Pavlak
alex@pavlak.net

Apollo

A strategic systems engineering success



Strategic goal

"We will put a man on the moon before the end of the decade and return him safely to earth"

JFK May 25, 1961

Dr. Alex Pavlak
alex@pavlak.net

Overall Strategic Goal

- Big reductions in fossil fuel consumption is inevitable
  - Fossil fuel is a finite resource
- Flexible time frame
  - Environmental concerns and climate change may accelerate schedule
- Consistent with Obama's Copenhagen goal
  - 83% reduction of CO_2 emissions below 2005 levels by 2050

Big (90%) reductions in greenhouse gas emissions

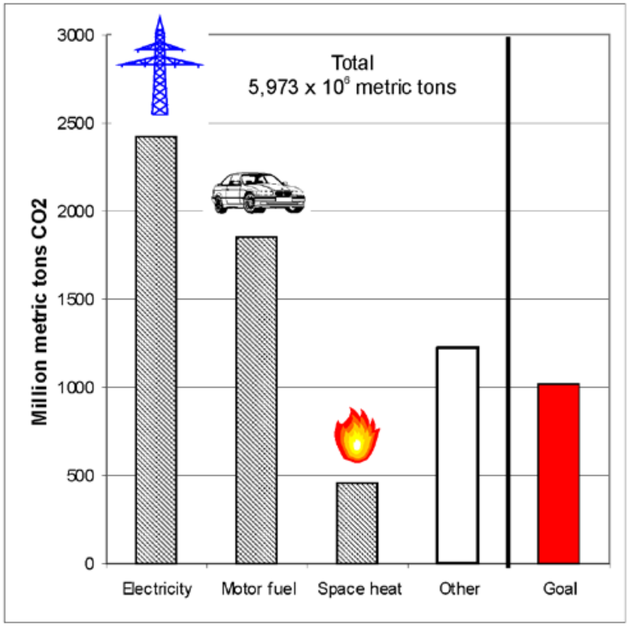
Dr. Alex Pavlak
alex@pavlak.net

Allocated Requirement

- Red bar represents Obama's Copenhagen of 17% residual emissions

- "Other" includes difficult to eliminate applications
  - Chemical industry
  - Fuel for aircraft

- Zero carbon electric power allows many fossil fuel applications to be shifted to electricity



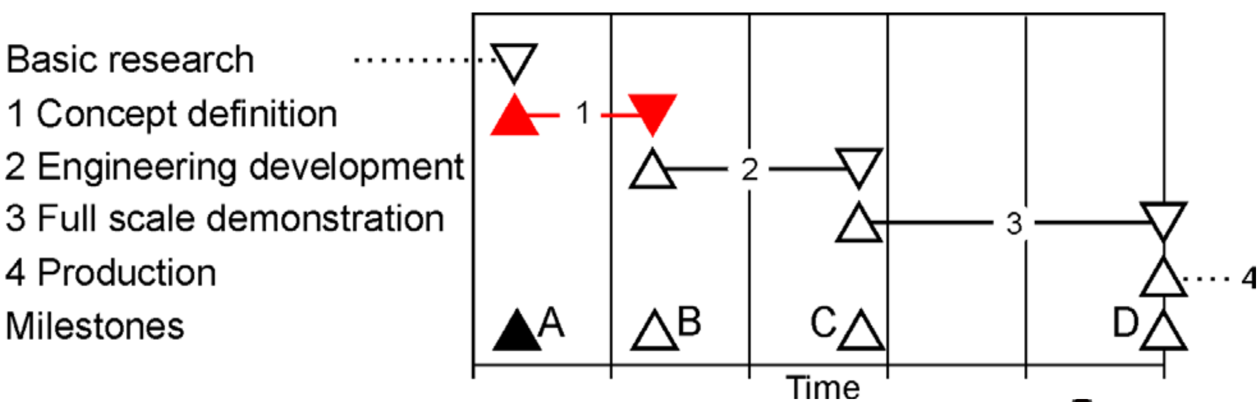
America's CO_2 emissions 2005

Zero carbon electric power

Dr. Alex Pavlak
alex@pavlak.net

Concept Definition Phase

- Develop the full range of feasible scenarios
  - Based on goals (m/s A) and known technology
  - Establish technical constraints
- Compare them, tradeoffs
  - Provide technical recommendations
  - Society chooses a direction (m/s B), an informed value choice
- Phases 2, 3, 4 are agile



Dr. Alex Pavlak
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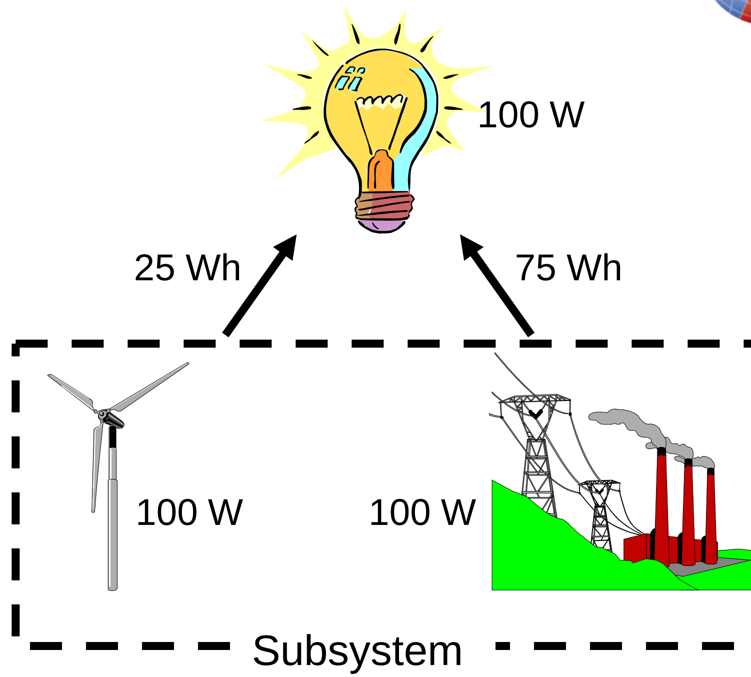
Electric Power System

- Systems Architecture 101
  - Systems are all about interfaces
  - **“Partition the system into functional components with simple interfaces”**
- Partitioning is critical with intermittent generators
  - Intermittent generators cannot stand alone
    - Must rely on “something else” to keep the lights on
  - Partitioning simplifies the interfaces

Dr. Alex Pavlak
alex@pavlak.net

Wind Scenarios

- Decompose the system
  - Closed, stand-alone subsystems
  - Subsystems have same reliability as traditional generators (~0.97)



1. **Wind systems may not be clean**
2. **Value of wind is wholesale cost of fossil fuel**
3. **Wind has no peak capacity**

- Wind + (something else)
  - Wind + (fossil fuel)
  - Wind + storage
  - Wind + hydro
  - Wind + biomass
  - Wind + (long distance transmission)
  - Wind + geothermal
  - Wind + nuclear
  - Combinations

Dr. Alex Pavlak
alex@pavlak.net

Other Scenarios

What are the best systems for reducing emissions?
Is there a dominant technology?

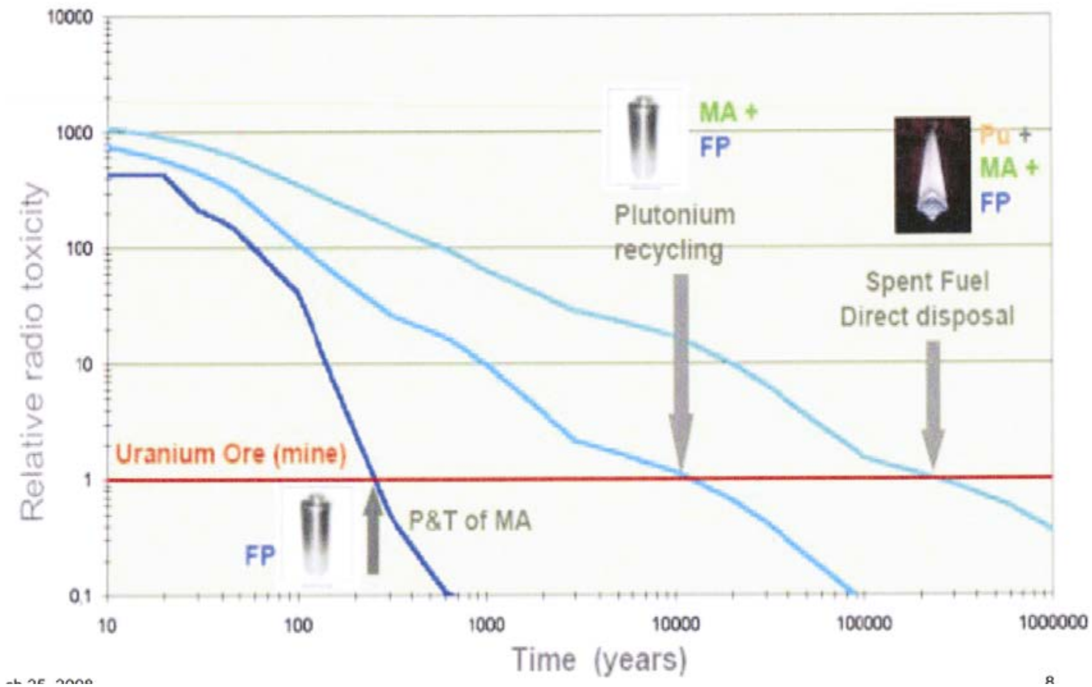
- Strategic scenarios are simple concept models of end state system configurations
  - Based on known technology
  - Ignore current policy and legacy systems
  - Anticipate probable improvements.
- Analyze systems in sufficient depth to capture the structural essence - but no more.
- Provide a clear definition of the technical feasibility of various choices.
- To be followed by design reviews, management decision milestones, policy.

- Electric power
  - **Nuclear**
  - Smart grid
  - Wind
  - Coal with CGS
  - Solar
  - **biomass**
  - **Geothermal**
  - Tides
  - Ocean thermal gradient
  - Storage
  - Hydro
- Motor vehicle fuels
- www.pavlak.net/FoE Scenarios.pdf

Dr. Alex Pavlak
alex@pavlak.net

Nuclear Scenarios

- Imagine 80% global nuclear power
  - Cheap
  - Safe
  - Sustainable ?????
  - Secure
- Legacy systems do not scale
  - Resource
  - Waste management
- Sustainable nuclear power
  - Breeders (U-Pu or Th-U)
  - Transmute long lived fission products

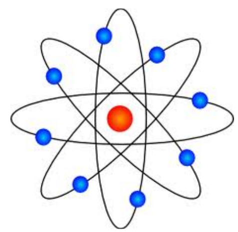


Nuclear fission has sustainable potential

Dr. Alex Pavlak
alex@pavlak.net

The French Model

- Electric power system 90% carbon free today
  - 80% nuclear
  - 10% hydro
  - 10% coal



- System design
  - Level diurnal variations with oversized hot water heaters & pump storage
  - Build reactors with modest load following capability
  - Eliminate fossil fuel

Wind

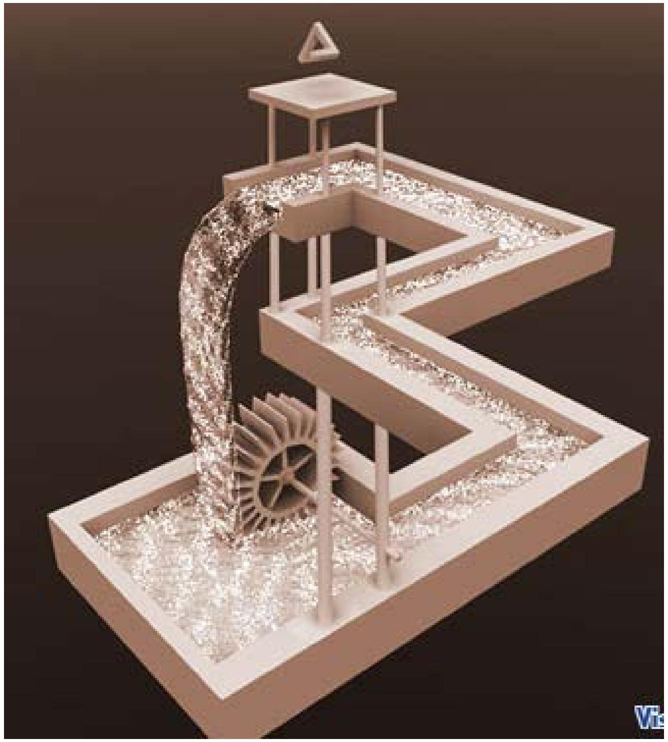
- Politicians mandating EdF to add wind turbines
- Must also add natural gas to satisfy load
- Increasing grid emission

Dr. Alex Pavlak
alex@pavlak.net

Open Critical Reviews

- Purpose
  - Does the system satisfy requirements?
  - Clarify issues and problems to be resolved
  - Provide a objective factual basis for value choices

- Open format
  - State requirements/goals
  - Fact finding Public hearing (webinar)
  - Compare the system with requirements
  - Publish comparisons seeking feedback
  - Upgrade and document analysis based on feedback.
  - Minority/majority technical opinions



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Future of Energy Initiative

Tasks

- Intermittent system scenarios
- Nuclear system scenarios
- Mentoring
  - Other system scenarios
- Critical reviews

Charter

- INCOSE-CC Initiative
  - Subgroup of INCOSE P&E working group
- Open source collaboration
- Partner with existing professional organizations
- Fund expenses for system scenarios development

Dr. Alex Pavlak
alex@pavlak.net

Global Leadership

- We have clear and stable goals
  - Big (90%) reductions in greenhouse gas emissions
  - Zero carbon electric power
  - Cheap, safe, sustainable and secure nuclear systems
- Next step is classic concept definition phase
  - System scenarios
    - Intermittent generators
    - Nuclear
    - Everything else
  - Novel methods
    - Open critical reviews
  - Identify technically feasible choices
  - Partner with appropriate organizations
- We live in a world with no one in charge
  - Special interests have too much influence
  - Enormous legacy inertia
  - Need open independent system design

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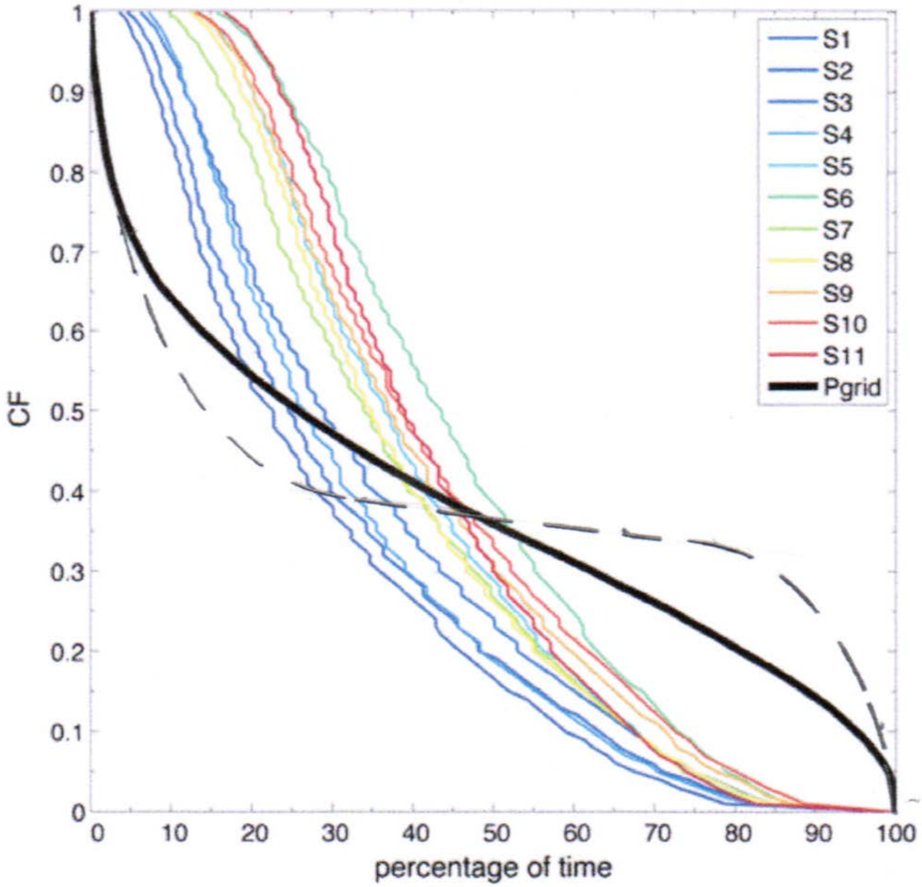
Power-%



U.S Offshore, East Coast

Kempton, W., et al, Electric power from offshore wind via synoptic scale interconnection, *Proceedings of the National Academy of Sciences* 107:16, pp. 7240-7245; supporting information, Figure S-3, available at: www.pnas.org/cgi/doi/10.1073/pnas.0909075107

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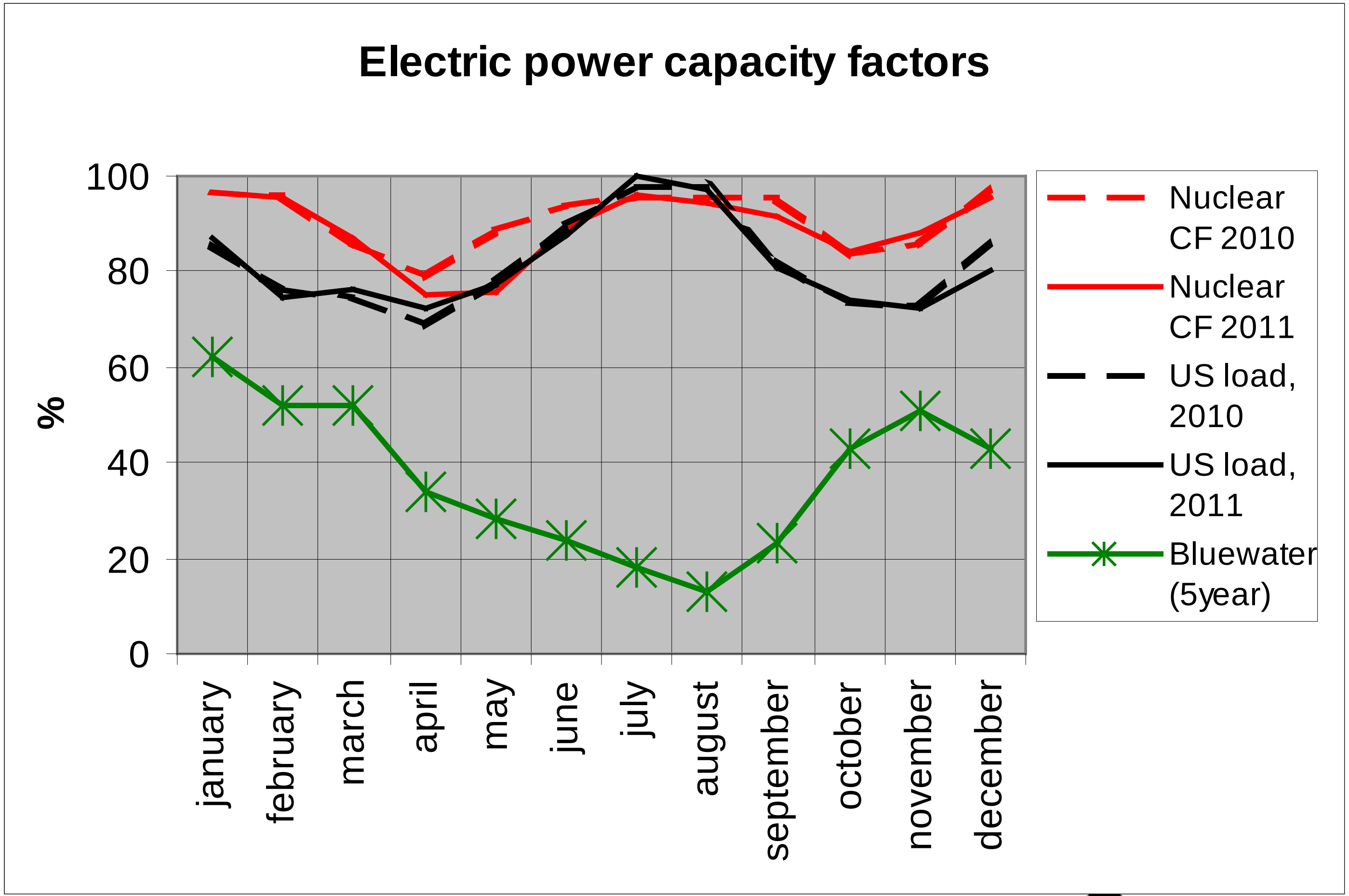
Capacity Factors



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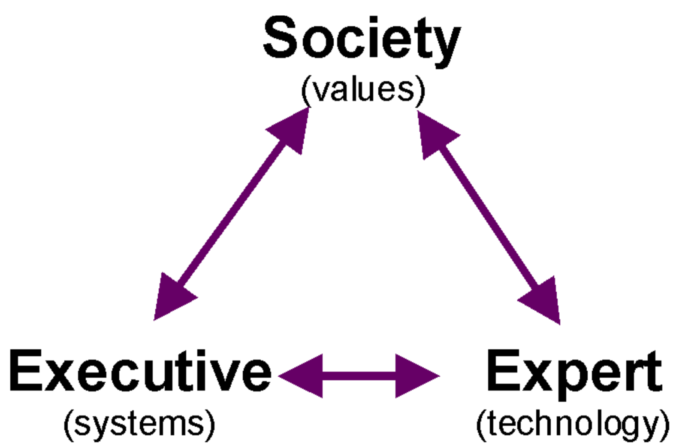
Architecture Governance



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

- Executive – INCOSE
  - – Balanced coordination between experts and society
  - – Encourages best practices: strategy, systems, design reviews
  - – Technology neutral
- Expert – Open source collaboration
  - – Responsible for technical analysis, research & development, technical coordination
  - – Technology bias
- Society
  - – Responsible for value judgment
  - – Chooses policy

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So Many Stakeholders!

- One challenge to clean energy systems development is the number, diversity and innumeracy of stakeholders
  - Energy affects everyone and everyone has an opinion
- Strategy will be to partner with existing professional organizations
  - Invited papers
  - Critical review sessions

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