



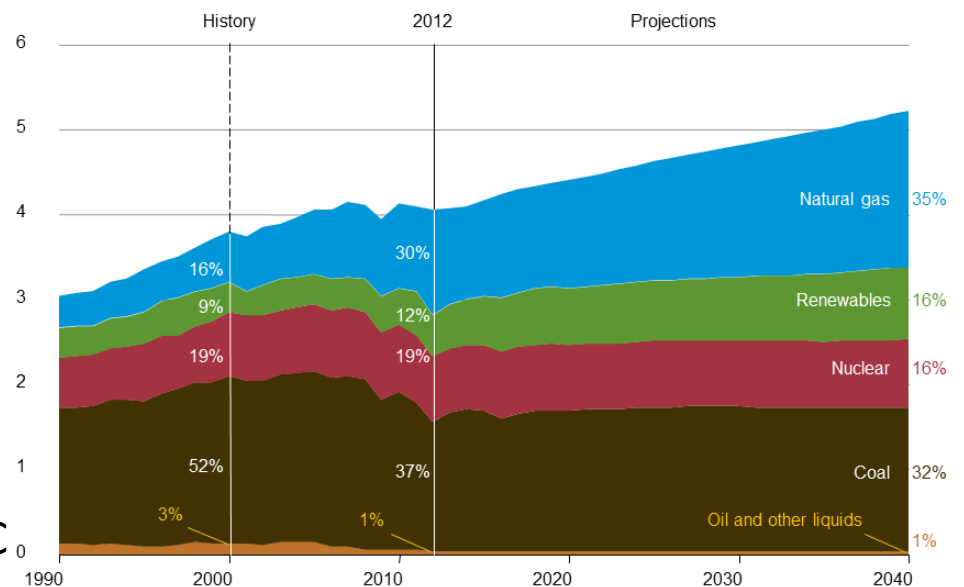
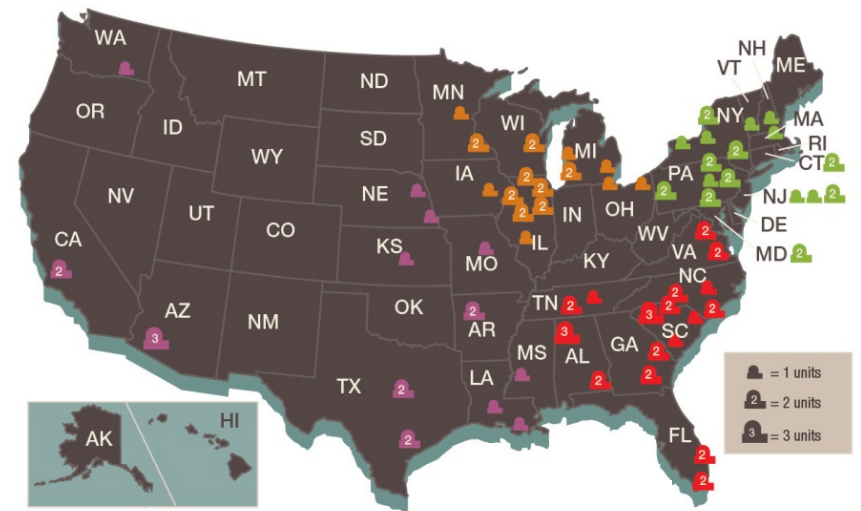
Transition to Autonomy: Parallels to the Nuclear Industry

NASA Ames Workshop
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Nuclear Power Generation

- 19% of US energy mix
- 99 operating nuclear power plants
 - ◆ 1969, Oyster Creek, NJ & Nine Mile Point 1, NY
 - ◆ 1996, Watts Bar 1, TN
- 4 new builds (license issued)
 - ◆ 2 units at Virgil C Summer, SC
 - ◆ 2 units at Vogtle, GA
 - ◆ Last approval was 1978 prior to Three Mile Island, 1979



Sources: EIA and USNRC

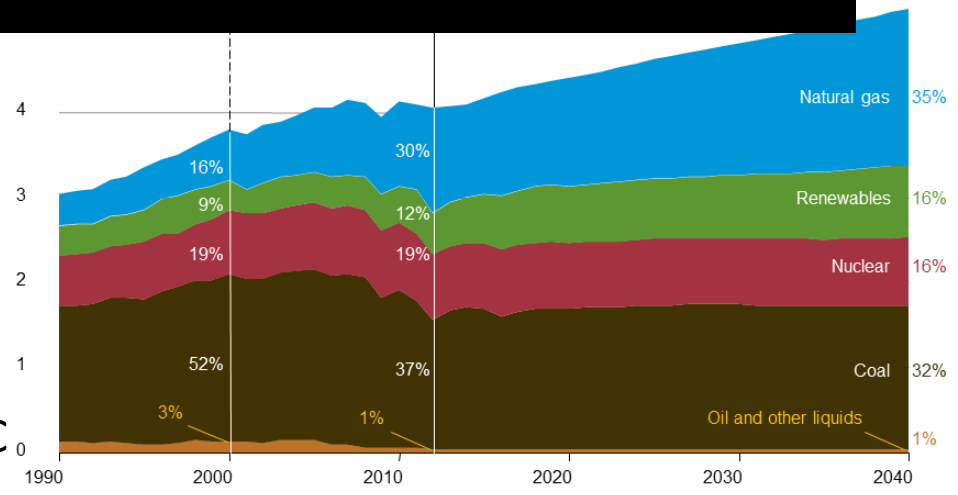
Nuclear Power Generation

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Mostly plants operate with old technology so the focus in the US has been attending to the viability of the existing fleet to support electricity production

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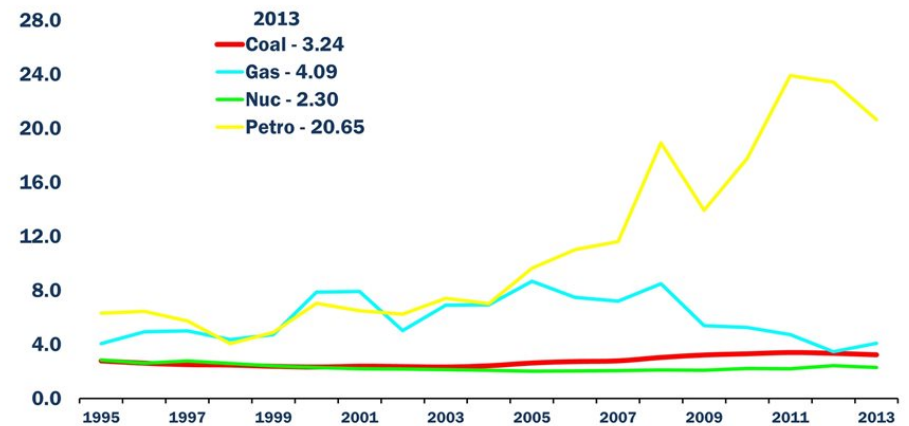


Driving Forces

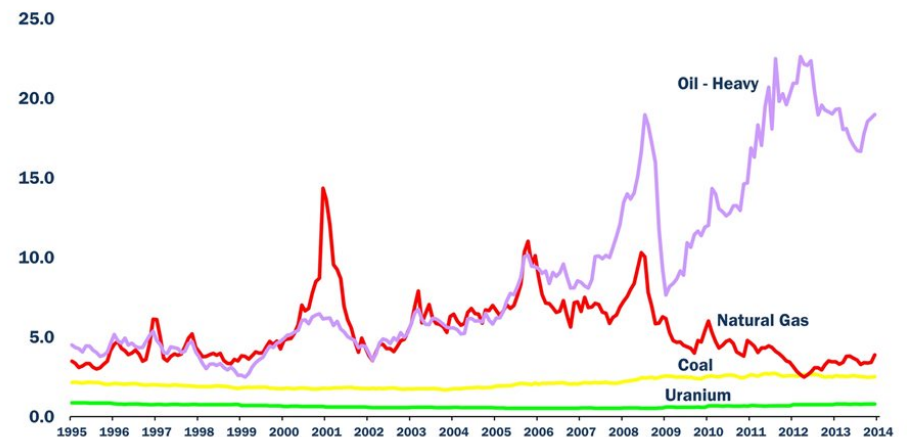
- Life extensions & uprates
 - ◆ 40-year license expiring
 - ◆ 20-year extension application
- Modernization
 - ◆ Obsolete analog equipment
 - ◆ Digital instrumentation & control (“fly-by-wire”)
- Economics
 - ◆ Low variable operations and maintenance/fuel (O&M) cost
 - ◆ High capital cost
 - ◆ High fixed O&M cost

Source: EIA

U.S. Electricity Production Costs
1995-2013, In 2013 cents per kilowatt-hour



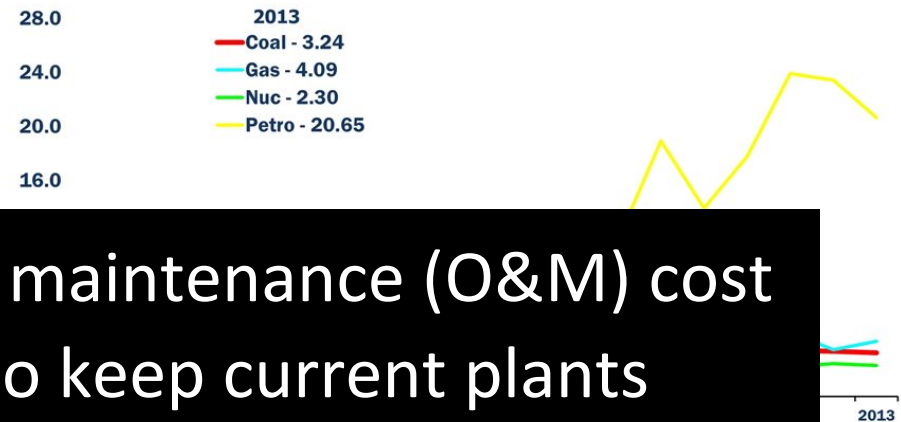
Monthly Fuel Cost to U.S. Electric Utilities
1995 – 2013, In 2013 cents per kilowatt-hour



Driving Forces

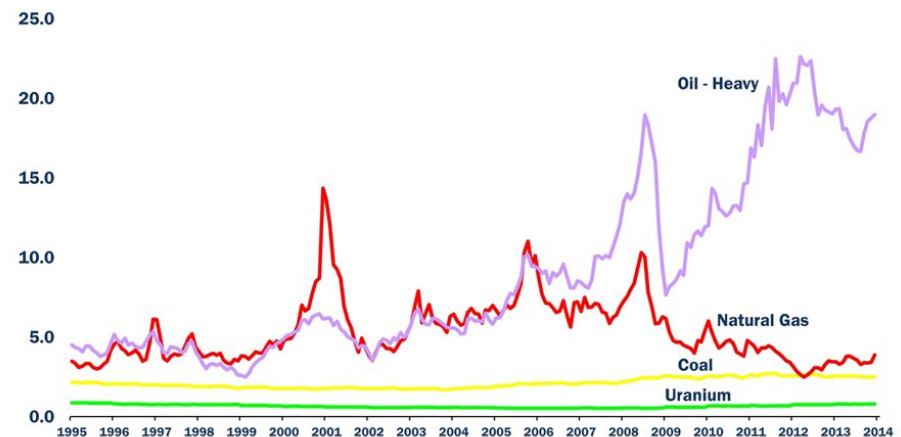
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U.S. Electricity Production Costs
1995-2013, In 2013 cents per kilowatt-hour



Low variable operations and maintenance (O&M) cost provide high incentives to keep current plants operating through life-extension licensing and upgrades

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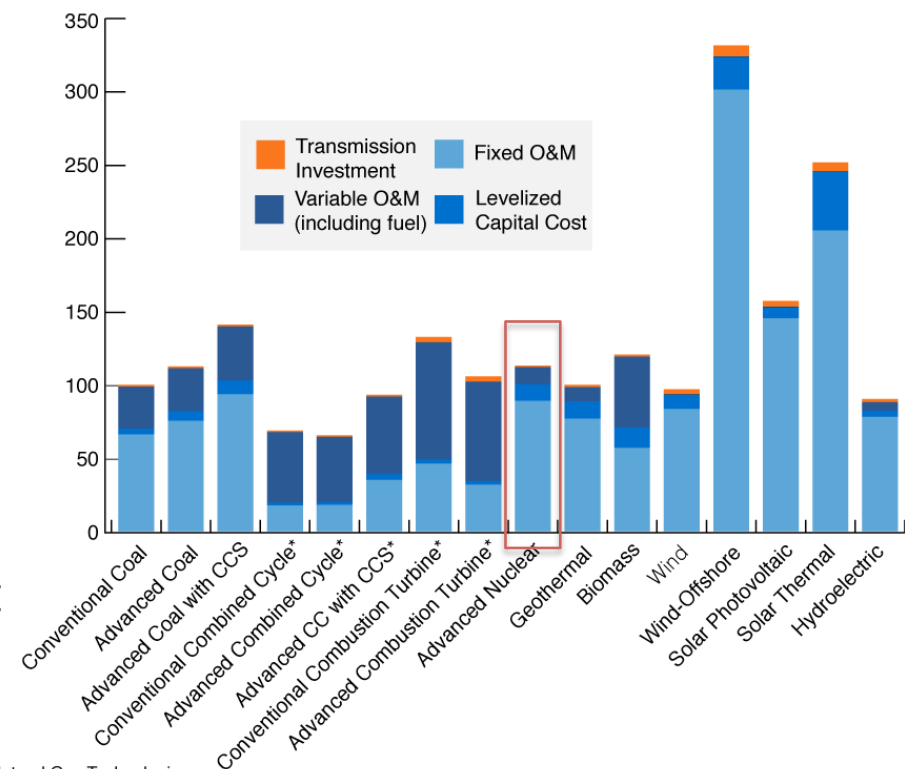
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Estimated Levelized Cost of New Electric Generating Technologies in 2017 (2010 \$/megawatthour)



*Natural Gas Technologies

Source: Energy Information Administration, Annual Energy Outlook 2012,
http://www.eia.gov/forecasts/aeo/electricity_generation.cfm

Driving Forces

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Estimated Levelized Cost of New Electric Generating Technologies in 2017 (2010 \$/megawatthour)



High fixed operations and maintenance (labor), and capital cost drive innovation in new reactor designs and automation

- ◆ Low variable operations and maintenance/fuel (O&M) cost
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*Natural Gas Technologies
 Source: Energy Information Administration, Annual Energy Outlook 2012,
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Major Research Areas

- New builds
 - ◆ Small Modular Reactor (SMR)
 - Prefabricated units
 - Retrofitting fossil fuel plants
 - CFR 50.54 Part 55 – staffing requirements
 - High level of automation for operating multiple reactors
- Modernization
 - ◆ Computer-based procedures (many levels – PDF vs “Autonomous”)
 - ◆ Alarm filtering/rationalization
 - ◆ Wearable devices for control room and field operator coordination
 - ◆ Upgrade with outages every 18 months
 - ◆ DOE Light Water Reactor Sustainability Project

mPower Integrated System Testloop at CAER



Major Research Areas

mPower Integrated System
Testloop at CAER

- New builds
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Small modular reactor designs can alleviate a lot risk in capital investment but regulatory exemption in control room staffing level via automation to be economical

levels – PDF vs Autonomous)

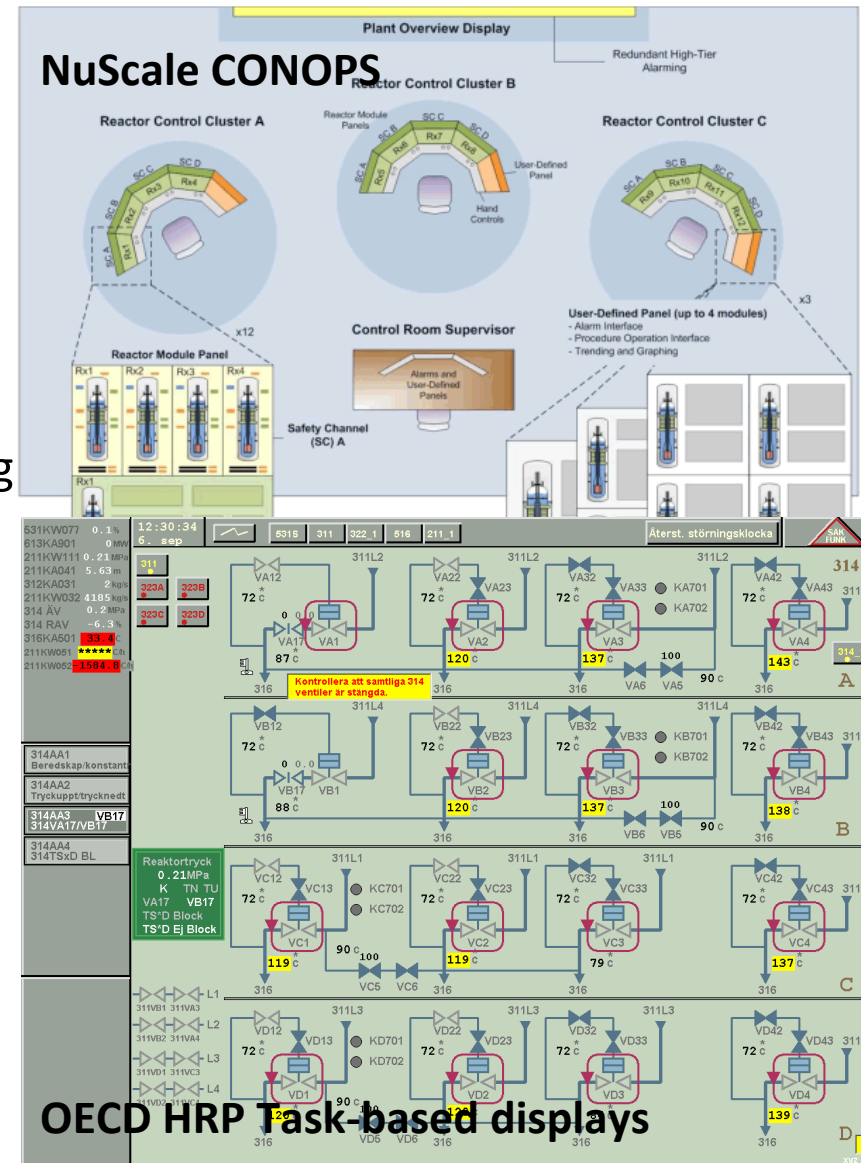
- ◆ Alarm filtering/rationalization

Note: “Increasing autonomy” for process plants are different from air traffic control or unmanned systems as process plants has a relatively “closed-loop “ design, though very complex.



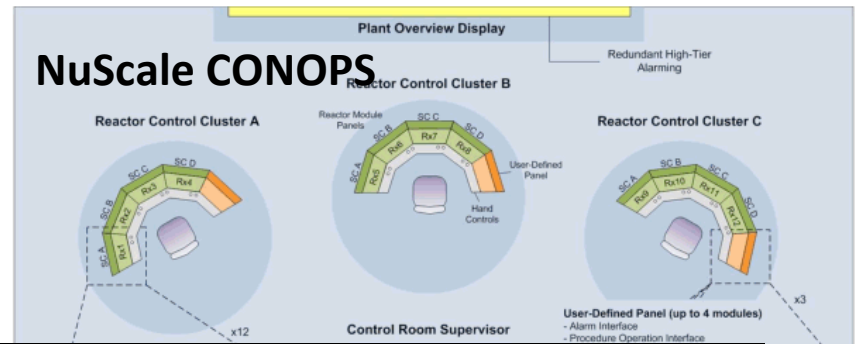
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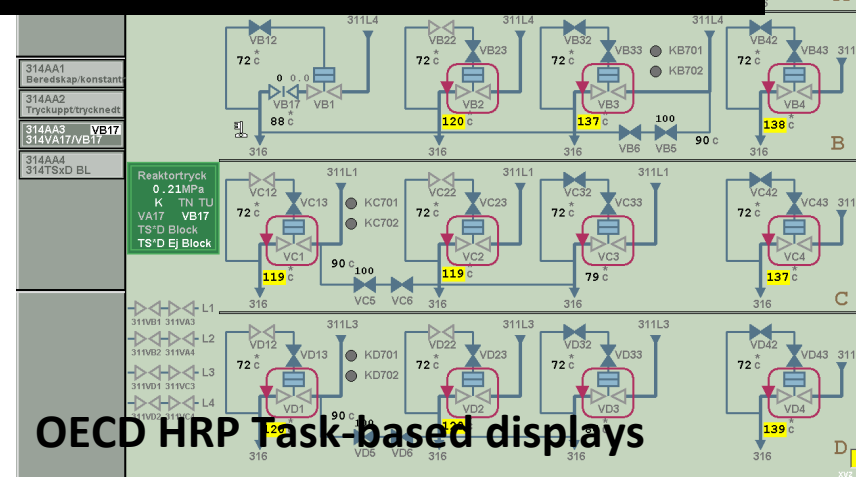
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Reducing labor/O&M cost by increasing automation of a plant become an important aim for the series of modernization projects (that can span over 10 years)

- (levels – PDF vs Autonomous)
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 - ◆ Wearable devices for control room and field operator coordination
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Automation in Nuclear and Aviation

Similarities	Differences
<p>“Increasing autonomous”</p> <ul style="list-style-type: none">• What is ideal “autonomy”?	<p>Different technology and cognitive skills</p> <ul style="list-style-type: none">• Process plants are relatively closed loop and thus autonomous at steady state even with primitive technology
<p>Safety-critical = Certifying/licensing (V&V)</p>	<p>Different levels of acceptable risks</p> <ul style="list-style-type: none">• Single nuclear accident can destroy the industry (TMI)
<p>Unanticipated events/beyond-design</p> <ul style="list-style-type: none">• Severe accidents	
<p>Economic motivation for change (rather than safety)</p>	<p>Different economic drivers</p> <ul style="list-style-type: none">• Transportation vs energy alternatives
<p>Slow pace of adoption</p>	<p>“Open” vs “closed” system</p> <ul style="list-style-type: none">• Sky vs Grid