Fuel Reliability Status & the Promise Initiative

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EPRI Fuel Reliability Program

CASL Industry Council
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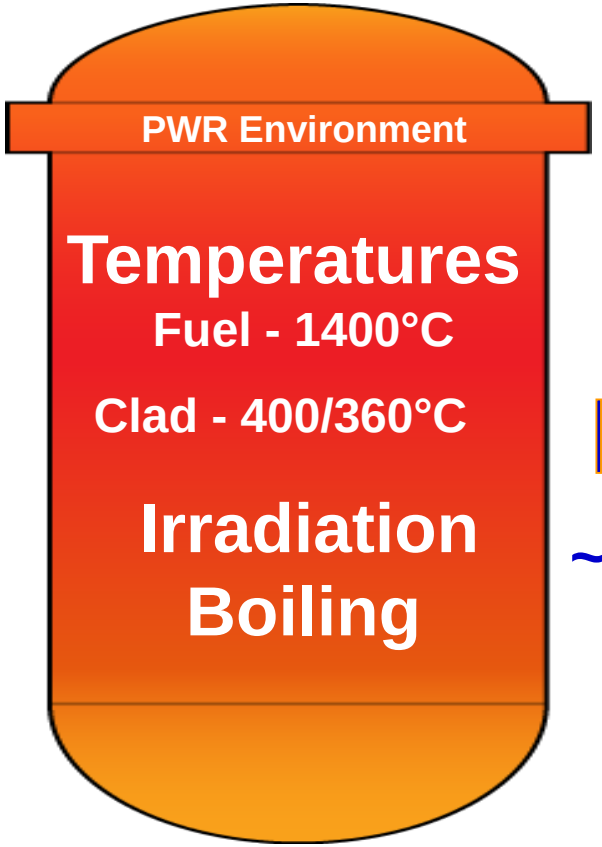
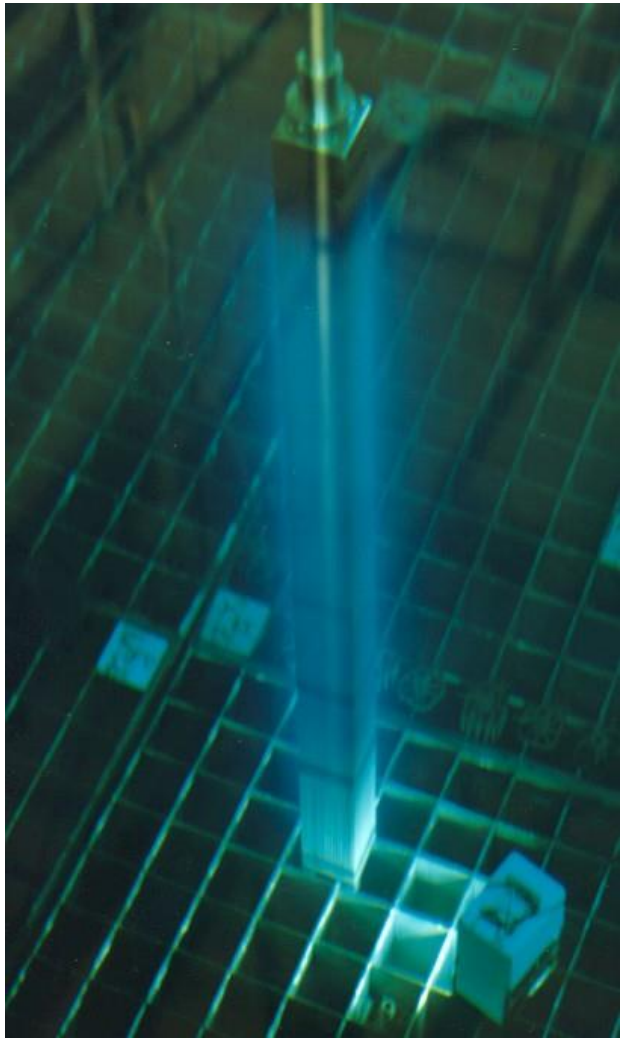
Challenges to Fuel Reliability



World Fleet

~16.8M Fuel Rods(1)



(1) Based on EPRI FRED and IAEA databases, includes BWRs, PWRs, VVERs, PHWRs

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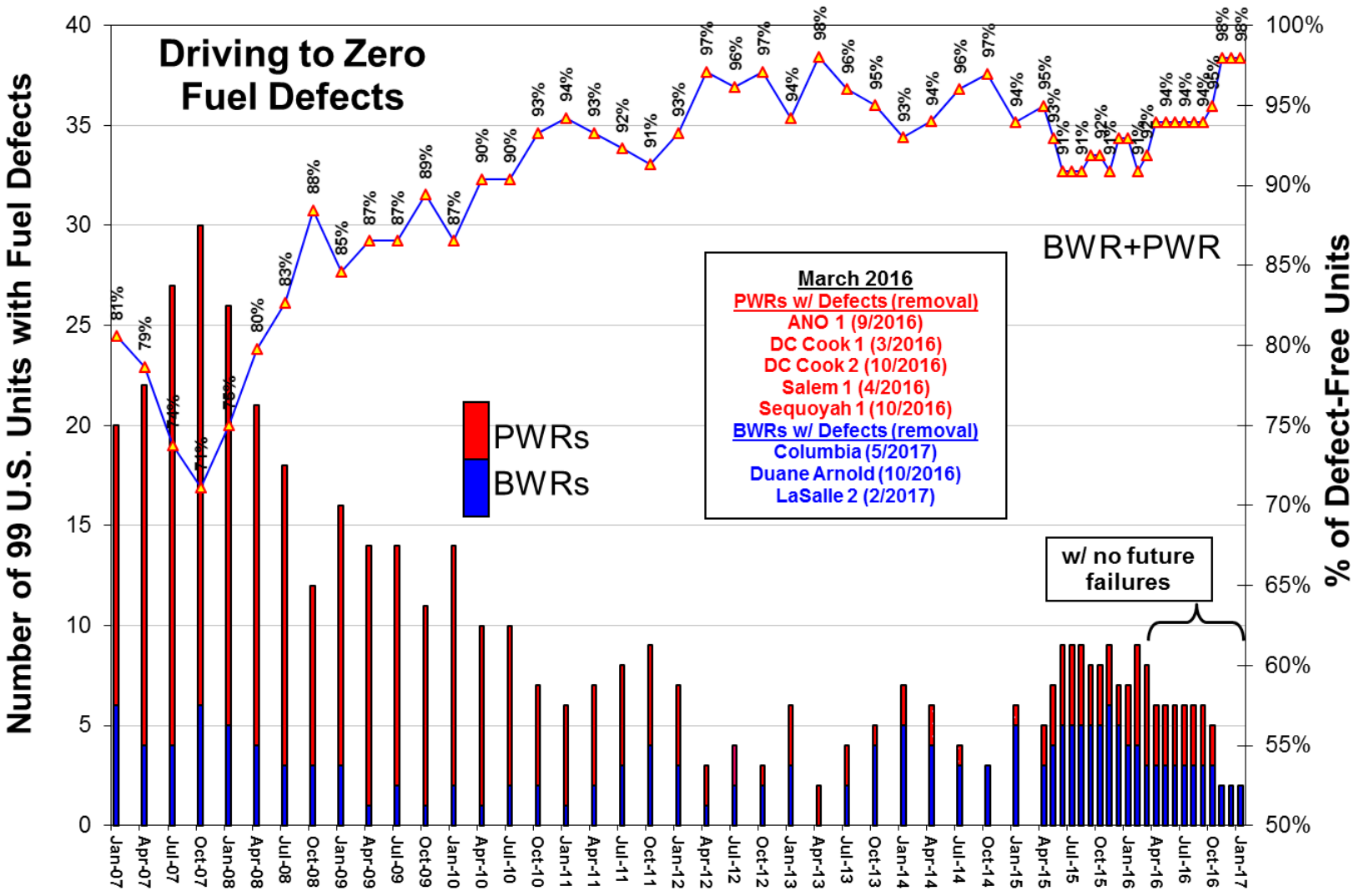
Fuel Reliability: U.S. Leaker Status



Courtesy:
Mike Reitmeyer
(Exelon)

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What Does a Fuel Failure Cost?

Type	Considerations	Cost, $	Total, $
B / P	Increased chemistry monitoring requirements	15,000	
B / P	Radiation management requirements (i.e., contamination areas / PCs)	30,000	
B / P	Increased primary water system cleanup costs	50,000	
B / P	Fuel sipping at EOC to identify leaking fuel assembly	150,000	
B / P	Personnel dose (estimated range: 3 to 10 additional Rem per outage)	210,000	
B / P	Lost energy costs from early discharge of leaking fuel assembly (# burns depend.)	300,000	
B / P	Fuel inspection and root cause evaluations to determine the leaker root cause and to develop and implement corrective actions to prevent recurrence	350,000	
B / P	Core redesign (scope dependent)	500,000	1,650,000
B	Power suppression of leaking fuel cell to avoid degradation (duration dependent)	500,000	
B	Power suppression testing (generation loss)	1,000,000	
B	Mid-cycle outage to remove leaker if excessive fuel rod degradation occurs (8 days - outage costs plus lost generation)	18,000,000	21,150,000

Courtesy:
Jim Lemons
(TVA)

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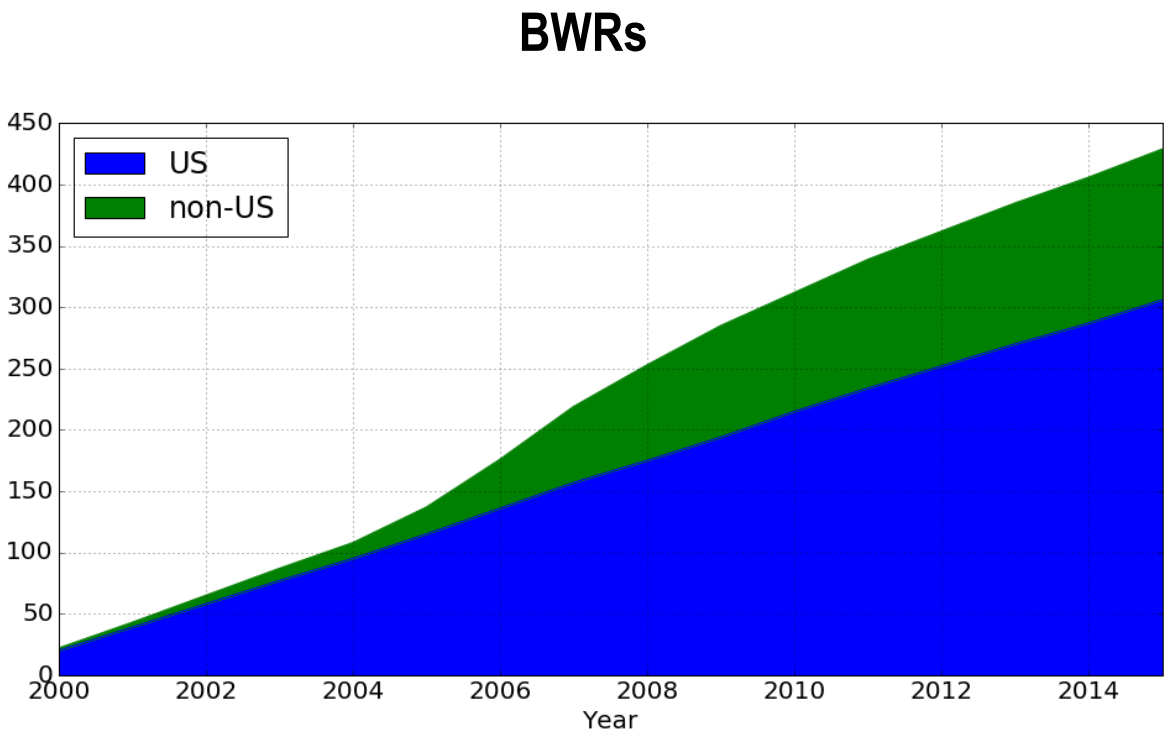
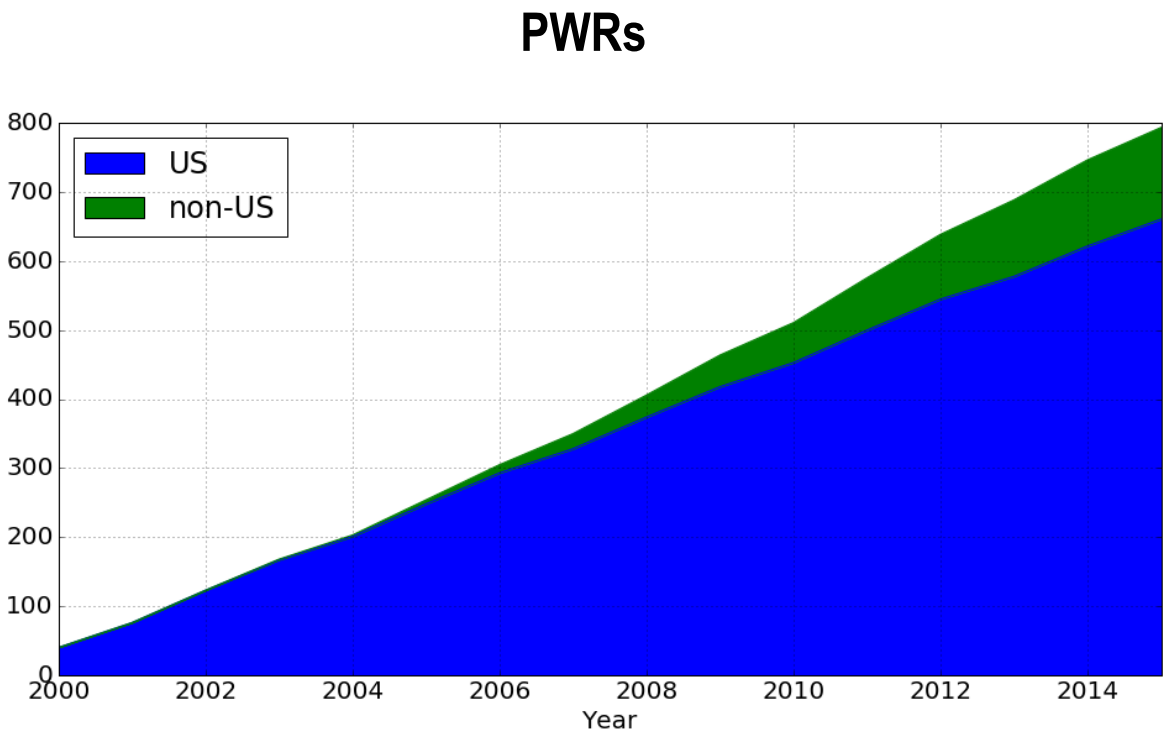
Trending FRED (Fuel REliability Database)





Large database on fuel performance for US, European and Asian plants. Statistics for non-US plants is non-uniform.

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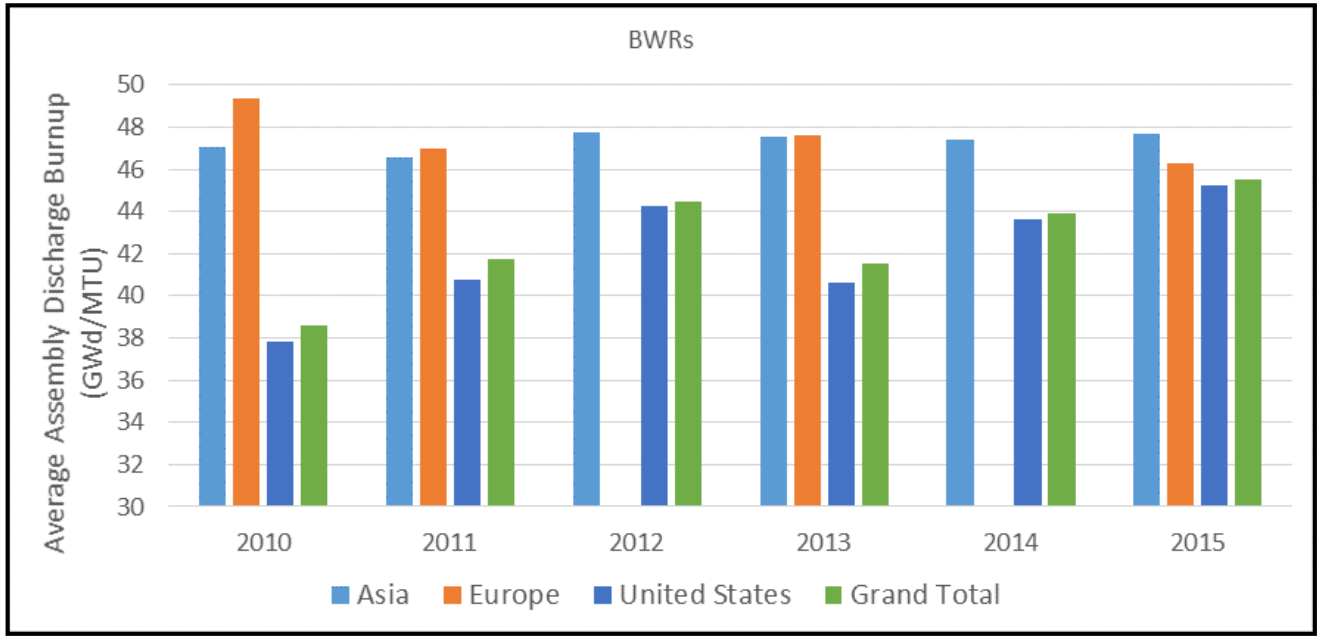
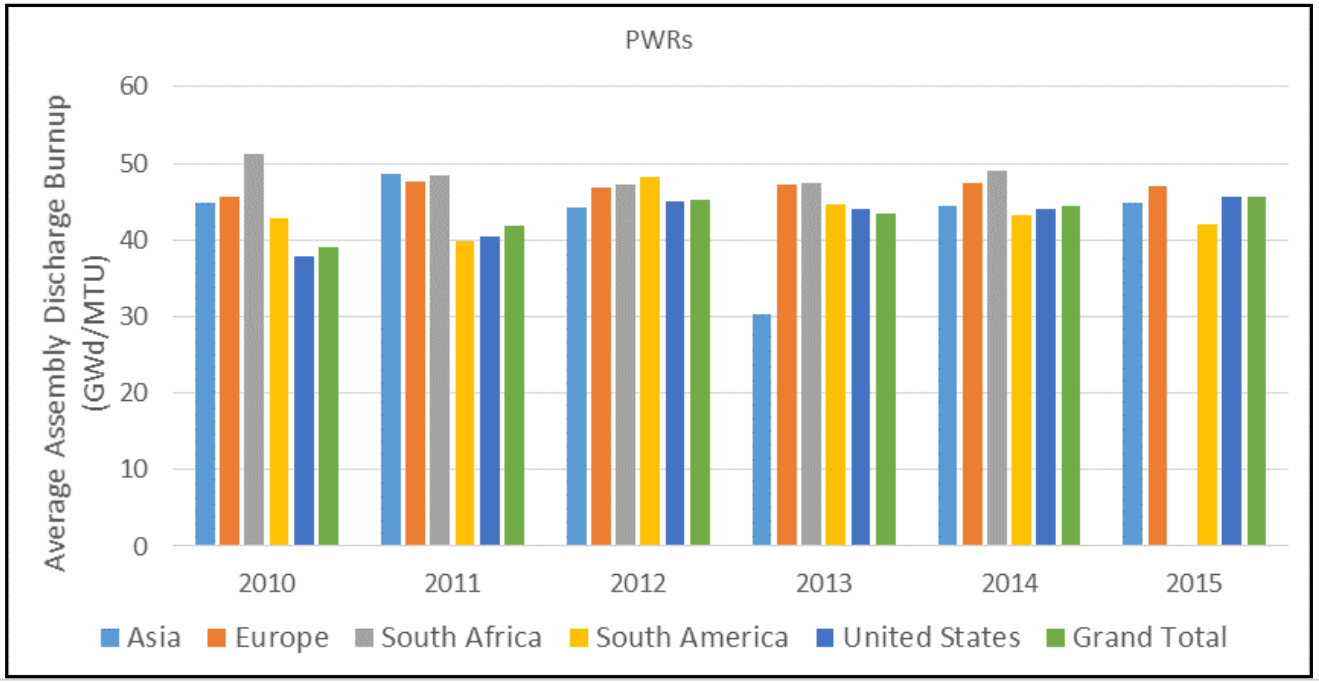
Average Discharge Burnup by Region

- Licensed burnup limits
  - PWR 62 GWd/MTU rod average
  - BWR 70 GWd/MTU peak pellet
- Fuel fragmentation LOCA issue needs resolution before increase in BU limits will be allowed





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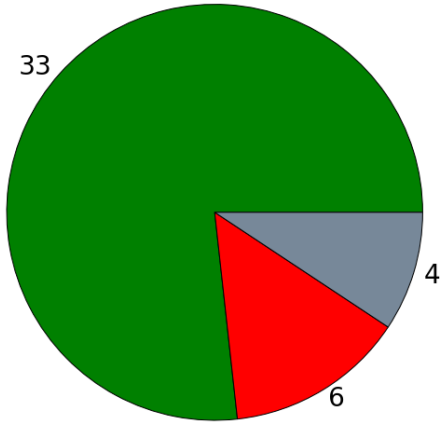
Fuel Reliability Update

Fuel failure mechanisms **by declared cycle failure category**

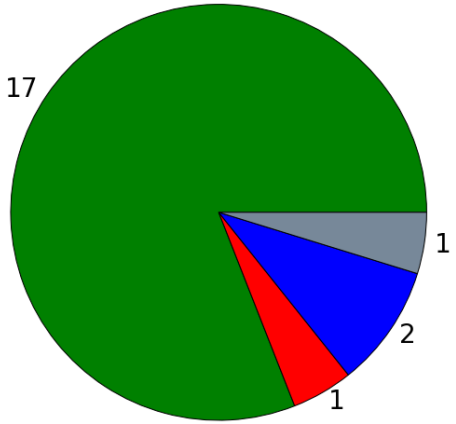
(1) Unknown includes Assessment in Progress, Inspected/Unknown, and Un-inspected

BWRs

2006 - 2010



2011 - 2015



- Grid-to-Rod Fretting
- Crud/Corrosion
- Duty-Related
- Debris
- Fabrication
- Unknown(1)

BWRs

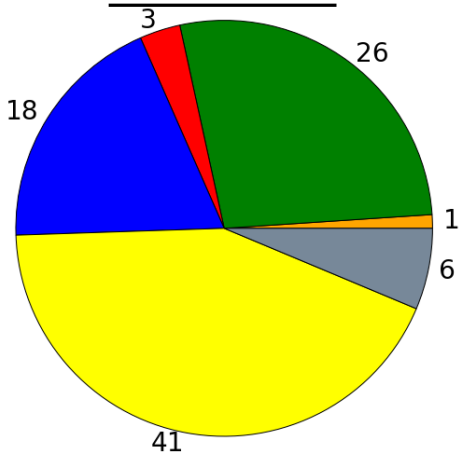
- Debris failure rate rate down **48%**
- Total failure rate down **51%** (9/year to 4/year)

PWRs

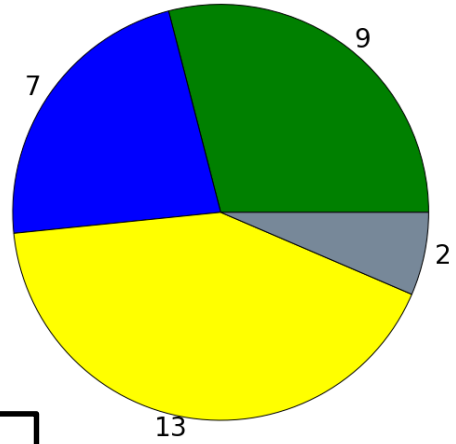
- GTRF failure rate down **68%**
- Debris failure rate down **65%**
- Total damage rate down **67%** (19/year to 6/year)

PWRs

2006 - 2010



2011 - 2015



No Mechanical Damage or Crud-induced failures in the past 5 years

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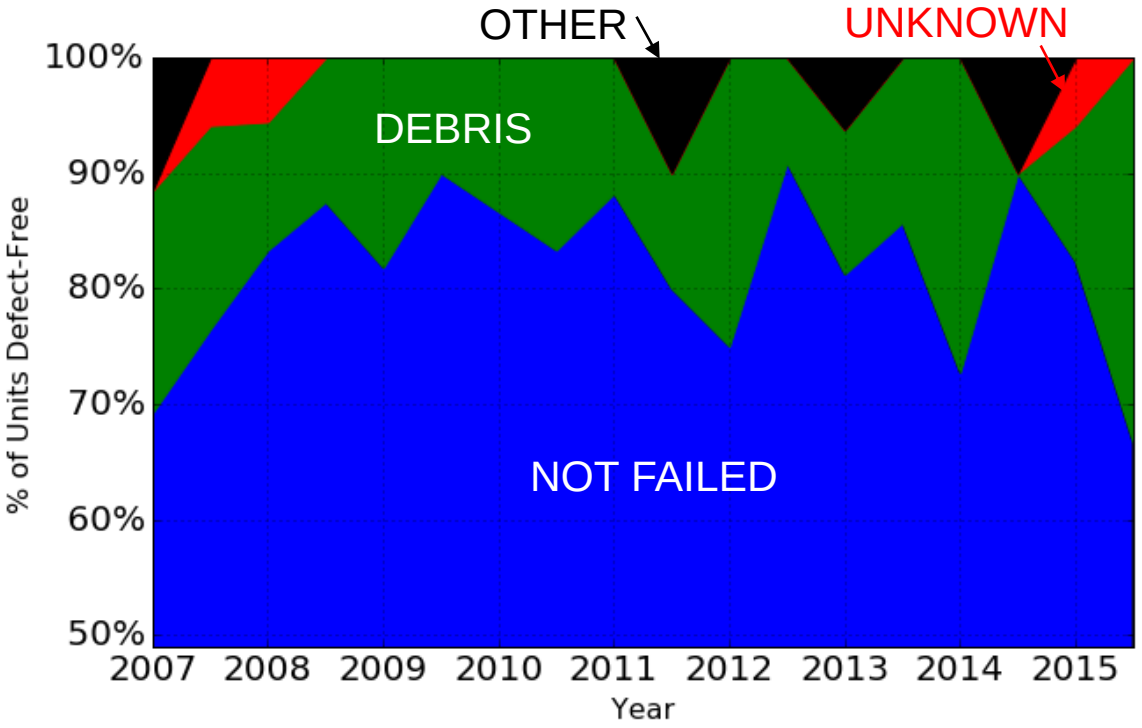
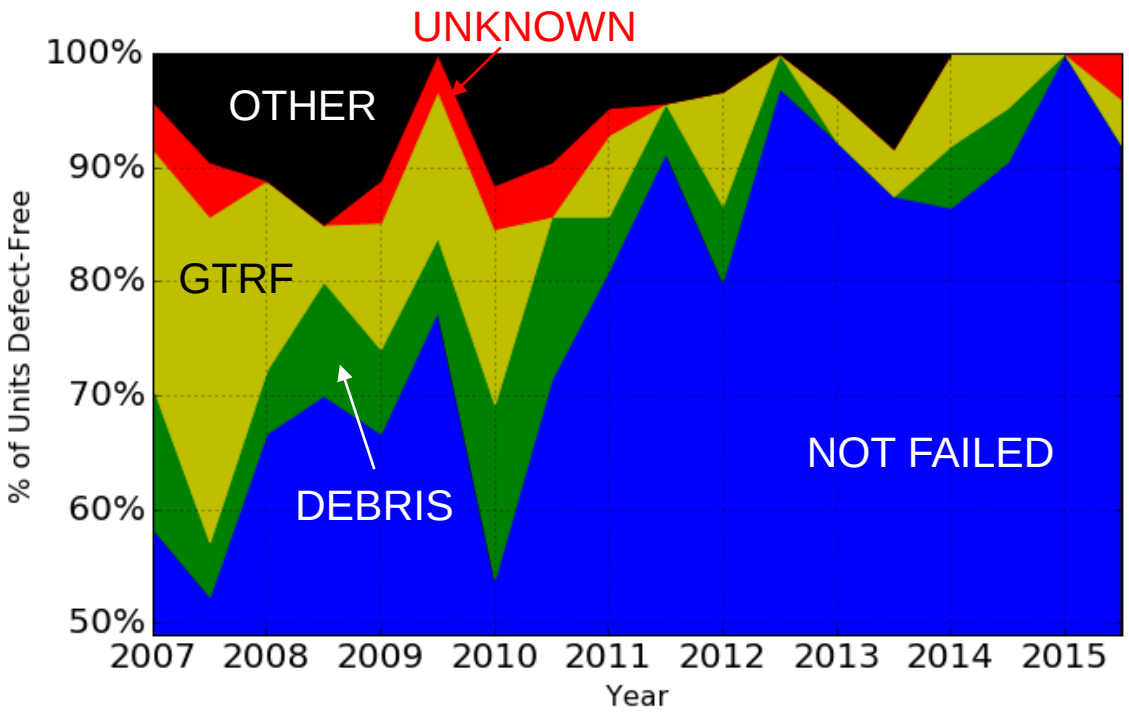
Fuel Reliability Update (Worldwide FRP Membership)

BWRs



PWRs



- BWRs: Debris is and has been the big issue
- PWRs: Debris and GTRF show significant decreases

OTHER includes fabrication, duty-related, primary hydriding, etc. failures

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Industry Snapshot

Uptick in U.S. Fleet Failures

- Increase in the number of leakers over the past couple years
- BWRs
  - Failure mechanisms
    - 11 debris
    - 1 duty-related
    - 2 TBD
  - Debris trend continues…
- PWR
  - Failure mechanisms
    - 5 GTRF
      - 3 of 5 involve baffle interaction/jetting
    - 3 debris
    - 5 TBD

~ Means failure type is not confirmed

(F) Signifies failed fuel type

Plant Type	Cycle	Shutdown	Fuel In Core	Failure
BWR (PFD)	19	Feb. 2014	GNF2 (F), GE14	Debris
BWR (Casc.)	26	Feb. 2014	GE14 (F), Optima2	Debirs
BWR (PFD)	16	Feb. 2014	GE14	~Debris
BWR (Casc.)	10	Oct. 2014	GE14 (F) ATRIUM 10	~Duty
BWR (PFD)	15	Feb. 2015	GNF2, ATRIUM 10 (F)	~Debris
BWR (PFD)	18	Feb. 2015	GNF2	~Debris
BWR (Casc.)	19	Apr. 2015	GE14	~Debris
BWR (PFD)	15	Apr. 2015	GE14	Debris
BWR (Casc.)	24	Nov. 2015 (MCO)	Optima2, SVEA-96 (F)	~Debris
BWR (PFD)	19	Jan. 2016 (MCO)	GNF2, GNF3	Debris
BWR (PFD)	20	Feb. 2016	GNF2, GE14	~Debris
BWR (Casc.)	25	Fall 2016	GNF2, GE14	~Debris
BWR (PFD)	16	Feb. 2017	GNF2, ATRIUM 10, GNF3	?
BWR (Casc.)	23	May 2017	GE14	?
PWR	20	Mar. 2014	CE	GTRF
PWR	21	Mar. 2014	CE-Turbo (F), HTP	GTRF
PWR	19	Apr. 2014	CE-NGF	Debris
PWR	37	Apr. 2014	422V+	Grid/Baffle
PWR	23	Sep. 2014	Adv. Mk-BW (F), RFA2	Grid/Baffle
PWR	21	Fall 2015	CE	Grid/Baffle
PWR	22	Nov. 2015	RFA	~Debris
PWR	26	March 2016	Upgrade DRFA	?
PWR	24	Spring 2016	RFA	?
PWR	22	Fall 2016	OFA Balanced Vane	?
PWR	26	Fall 2016	Mk-B-HTP	~Debris
PWR	21	Fall 2016	Mk-BW, AFA, HTP	?
PWR	27	Spring 2017	15UPG	?

operating

operating

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Recent Fuel Failures & Other Issues in Non-U.S. Fleet

Fuel Failures:

- BWR (Switzerland) – dryout failure & elevated corrosion indications in following cycle
- BWR (Spain) – two debris failures requiring mid-cycle outage discharge; one in current cycle
- PWR (Sweden) – unknown requiring mid-cycle outage discharge due to EPU requirements
- PWR (Brazil) – unknown
- PWR (Spain) – unknown
- CANDU (Canada) – unknown or otherwise not disclosed
- VVER (Hungary) – five unknown failures in the last three annual cycles

Notable Issues:

- Fuel handling events at Asian and European BWRs
- Crud induced power shifts (CIPS, or AOA) in Asian PWR

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Delivering the Nuclear Promise

Making nuclear power more cost efficient …

Target of 30% savings in generating costs

Slides adapted from Sam Belcher's (FENOC CNO) presentation to the FRP Action Plan Committee in Austin, Texas on February 10, 2016

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Delivering the Nuclear Promise: Advancing Safety, Reliability and Economic Performance

- Provide the genesis of this new initiative
- Describe the goals and objectives
- Describe the organizational structure and governance
- Our roles in this industry initiative

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Genesis of The Initiative

- The U.S. commercial nuclear industry is operating in electricity markets that are deluged with natural gas at historically low prices
- Nuclear industry capacity factors and reliability are at extraordinary levels … but total generating costs at nuclear plants have increased 28% in the last 12 years
- “Business as usual” approach will not successfully address the challenges of rising costs and inadequate revenue

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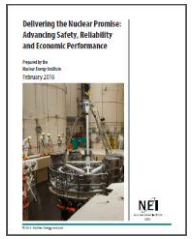
Increasing Plant Costs

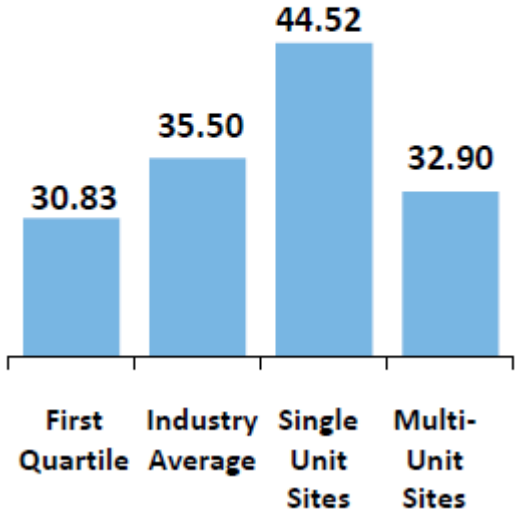
12-Year Trend of Nuclear Plant Costs 2014 $ per Megawatt-hour				
YEAR	FUEL	CAPITAL	OPERATING	TOTAL
2002	5.72	3.92	18.59	28.23
2003	5.59	4.93	18.84	29.37
2004	5.28	5.65	18.54	29.47
2005	5.02	5.80	18.95	29.77
2006	5.04	5.56	19.21	29.81
2007	5.13	6.12	19.07	30.31
2008	5.35	6.76	19.51	31.62
2009	5.93	8.91	20.49	35.33
2010	6.76	9.16	20.63	36.55
2011	7.10	10.06	21.88	39.04
2012	7.46	10.76	21.47	39.70
2013	7.73	8.20	20.93	36.86
2014	7.17	8.18	20.92	36.27
2002-14 INCREASE	**25%**	**109%**	**13%**	**28%**

From:
NEI Delivering the Nuclear Promise: Advancing Safety, Reliability and Economic Performance

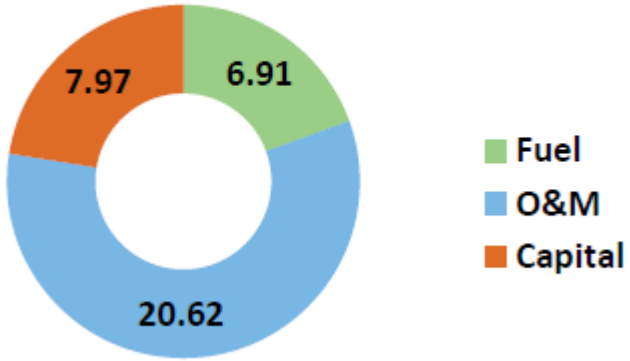


2015 Average Generating Costs

($ / MWh)



2015 Generating Cost



Source: Electric Utility Cost Group

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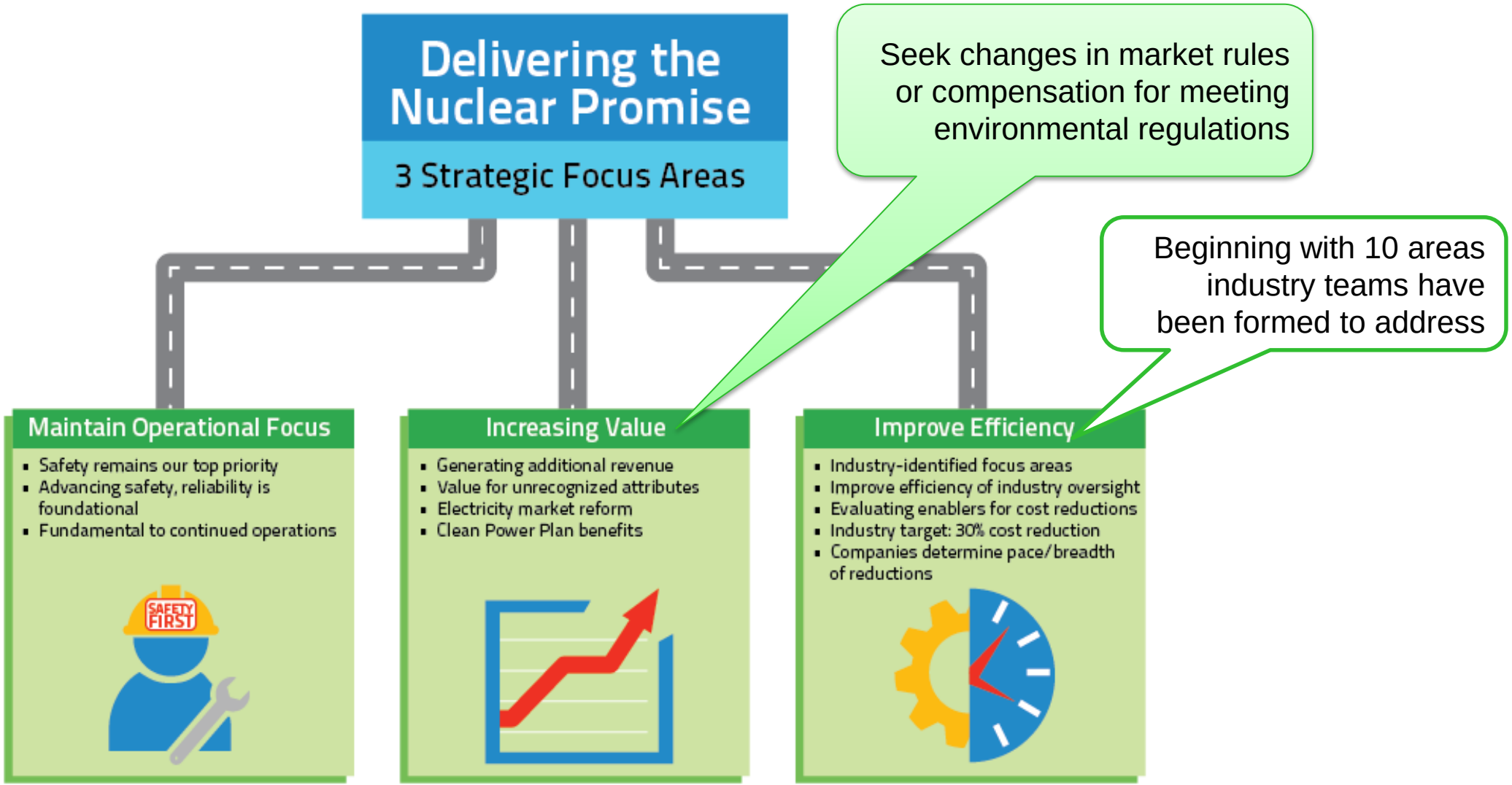
Industry's Response To The Challenge



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Building Block 1: Analysis & Monitoring

- Objective: Analyze plant cost drivers [common to all plants] and identify opportunities to improve efficiency
- Utilities leading this effort in working group
- CNO-led teams are drilling down into each area
  - ✓ Identify improvements, metrics & success criteria
- Will launch separate activities and inform Building Block 3 efforts

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Analysis & Monitoring

Goal: Provide utilities with innovative solutions that enable significant reduction in expenses across the fleet by 2018

Building Block 1 Teams with CNO Leads

1. Corrective Action Program—Danny Bost, Southern Nuclear
2. Engineering—Tim Rausch, Talen
3. Preventive Maintenance Templates—Neil Wilmshurst, EPRI
4. Radiation Protection—Fadi Diya, Ameren Missouri
5. Regulatory Efficiency—Mano Nazar, NextEra Energy
6. Security—Bryan Hanson, Exelon
7. Training—Randy Edington, APS
8. Work Management Execution—Tim O'Connor, Xcel Energy
9. Work Management Preparation—Dennis Koehl, South Texas Project
10. Inventory (Added) —Adam Heflin, Wolf Creek

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Building Block 2: Value Recognition

- Objective: Leverage federal, state policies to ensure recognition of nuclear energy's value in electricity pricing
- Encourage urgency at FERC, RTOs to address defects in competitive market practices
- Ensure EPA's Clean Power Plan (CPP) and state implementation plans recognize value of nuclear power plants
  - CPP: Reduce carbon emissions by 32% by 2030*
  - New reactors and uprates by existing plants for carbon credits by EPA's policy

* see next slide

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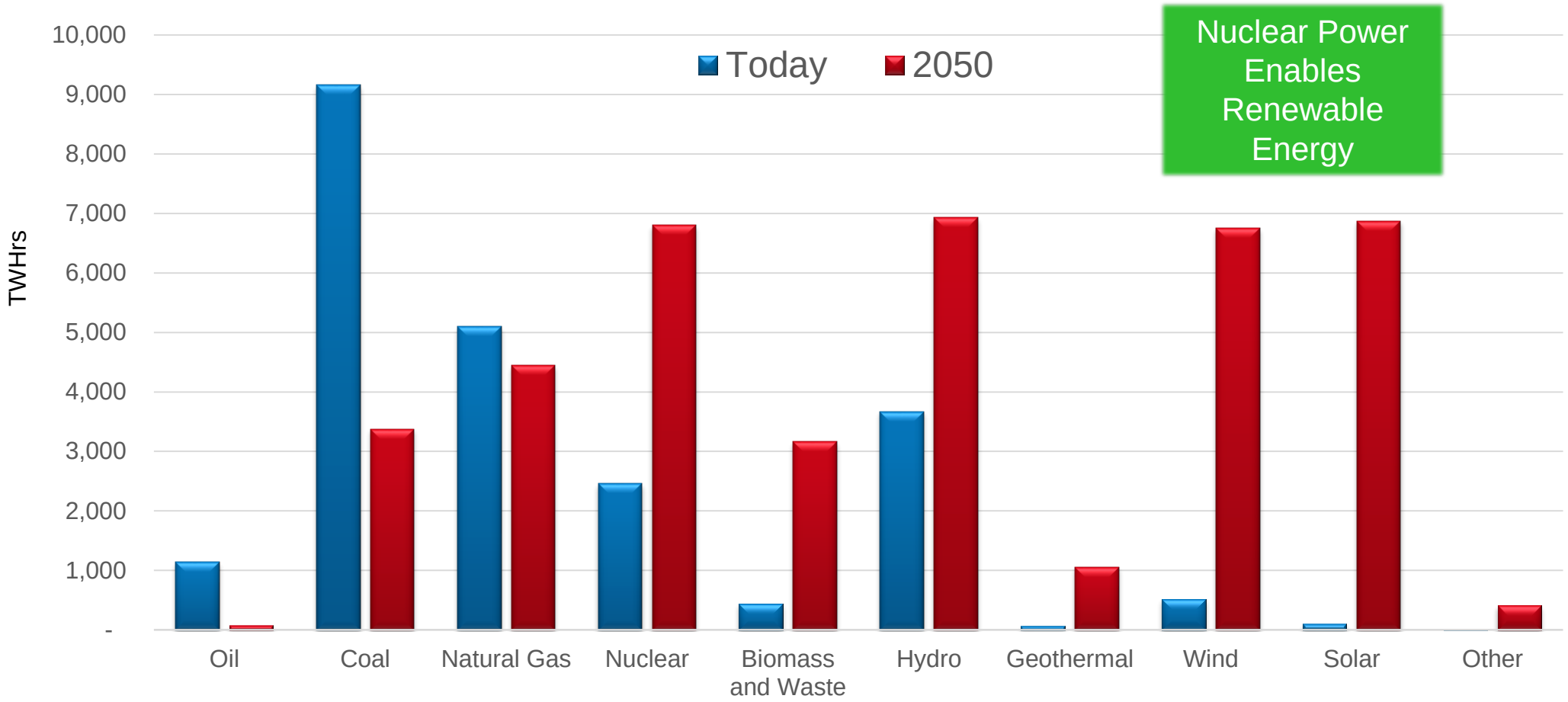
Global Electricity: A Look to 2050

slide presented by EPRI CEO, Mike Howard, to Nuclear Power Council in Feb. 2016



Source: IEA, Energy Technology Perspectives 2015. Note: 2050 Assume +2C Scenario. 662,863 PJs

76% Increase in Electricity Gen. – Shift from Fossil to Low-CO2 Emission Technologies

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Building Block 3: Process/Program Redesign To Advance Safety, Reliability And Efficiency

- Capture near-term efficiency improvements that can be done under existing guidance
- Re-design selected processes to improve efficiency while advancing the fundamentals of safe, reliable operation
- Address any impediments to implementation: existing guidance/procedures, regulatory or technological issues

Should teams in Building Block 1 identify opportunities to reduce costs and/or improve efficiency, those recommendations would be transferred to Building Block 3

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Building Block 4: Strategic Communications

- Objective: Implement communications, industry change management and advocacy programs
- Focus on employee engagement and alignment that results in broad industry participation
- Advocate greater value recognition for nuclear power plants in markets and policy (Clean Power Plan)

To succeed, this initiative requires total alignment across the industry

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Synergies with Nuclear Promise Initiative
What can we do?

- Nuclear fuel comprises up to 1/3 of generating cost
- Fuel is <u>not</u> a line item in the Initiative
  - But we can have a [significant] role to play
- Maintain focus on fuel reliability and safety by utilizing the industry standards we have collectively developed and update periodically
- Share your expertise
- Think creatively about R&D activities that can support the Nuclear Promise Initiative. Real difference makers often come from thinking WAY OUTSIDE the box

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Summary

- Fuel reliability is at an all time high but has recently plateaued
  - Debris-related failures are the dominant leaker mechanism
  - PCI, GTRF, crud / corrosion leakers have decreased
- Operational issues persist (channel distortion, fuel assembly distortion, CIPS/ AOA, fuel handling issues)
- Avoiding costs from leakers & operational issues are high priority
- CASL will have to contribute value in a *Delivering the Nuclear Promise* environment

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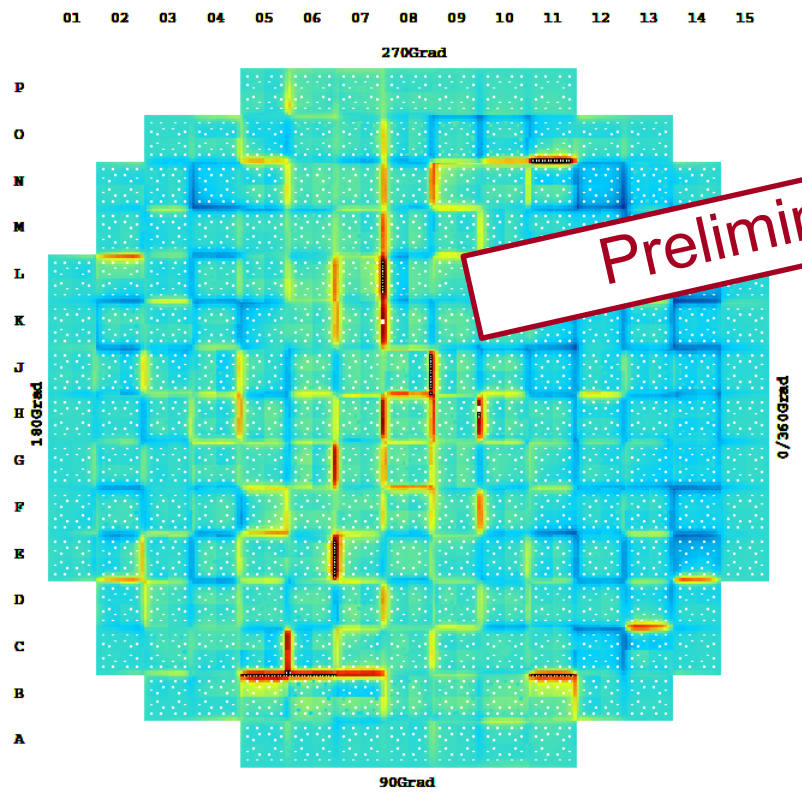
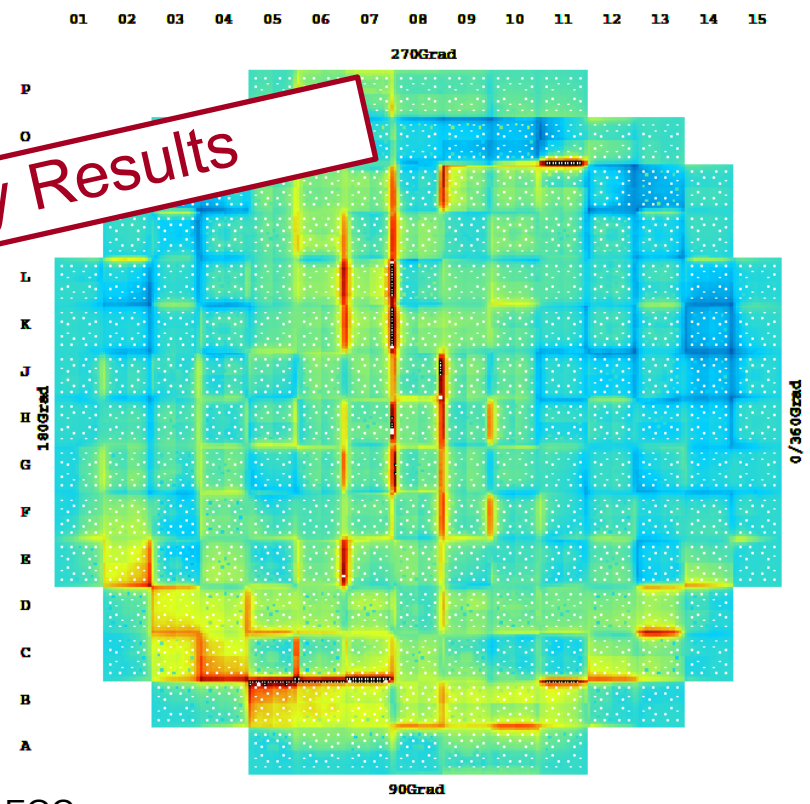
Fuel Assembly Distortion Application

- Neutronic computation of water gaps
- T&H effect on DNB margin is needed to address regulator questions
- Is CASL ready?

Significant increase in local linear heat generation rate (W/cm)



BOC



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Preliminary Results

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CASL Value Proposition Questions

- Existing methods have resulted in very good fuel performance
- CASL must deliver value over existing methods
  - Improved understanding of margins will enable better fuel utilization
    - CIPS – potentially 4 fresh bundles / reload
    - PCI - faster return to power
    - Burnup limits – LOCA fuel fragmentation issue needs resolution
    - LOCA, RIA, GTRF, DNB, FAD
  - Improved operational flexibility
- How / when will CASL products be delivered?
  - To whom?

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Together…Shaping the Future of Electricity

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