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Technical Solutions to Reduce Carbon

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Forum: “Climate Change, Research and Resources & Reliability”

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July 13, 2016

- **What's Coming Next?**

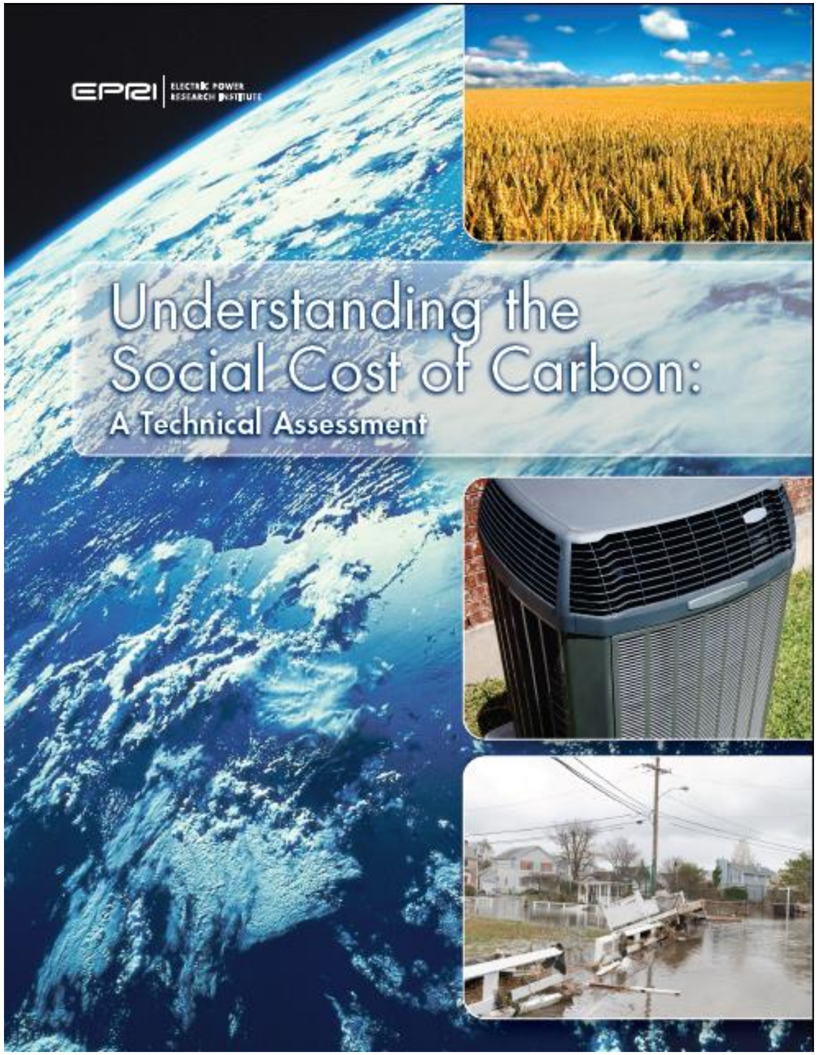
1. **Reducing Carbon Context:**
    - Understanding Social Cost of Carbon
    - What is "Climate Resiliency"?
2. **Producing Cleaner Energy:**
    - Fossil Plants
    - Nuclear Power
3. **Using Cleaner Energy:**
    - Local Energy Networks
    - Hydrogen Economy
4. **Integrating Energy Resources:**
    - Energy Storage
    - Big Data Management
5. **Human Factor**

First Let's Look at Climate Change: "Urgent" … "Threat"

"[The nations]… recognizing that climate change represents an urgent and potentially irreversible <u>threat</u> to human societies and the planet and thus requires the widest possible cooperation by all countries."

Paris Agreement – COP21 – Dec. 2015

"Understanding The Social Cost of Carbon (SCC)"



Understanding the Social Cost of Carbon: A Technical Assessment

http://epri.co/3002004657

Authors: S. Rose, D. Diaz, G. Blanford, J. Bistline, F. de la Chesnaye, T. Wilson

Inform Public and Policy Discussion: Next Few Years Critical

The Social Cost of Carbon (SCC)

The Answer: $36 per metric ton of CO_2

The Question: What does $36 mean?

What risks to society?

Difficult to interpret and evaluate.

Social Cost of Carbon is an Estimate of Benefit of Reducing A Metric Ton of Carbon

The Social Cost of Carbon (SCC) is Not One Value

Revised Social Cost of CO_2, 2010 – 2050 (in 2007 dollars per metric ton of CO_2)

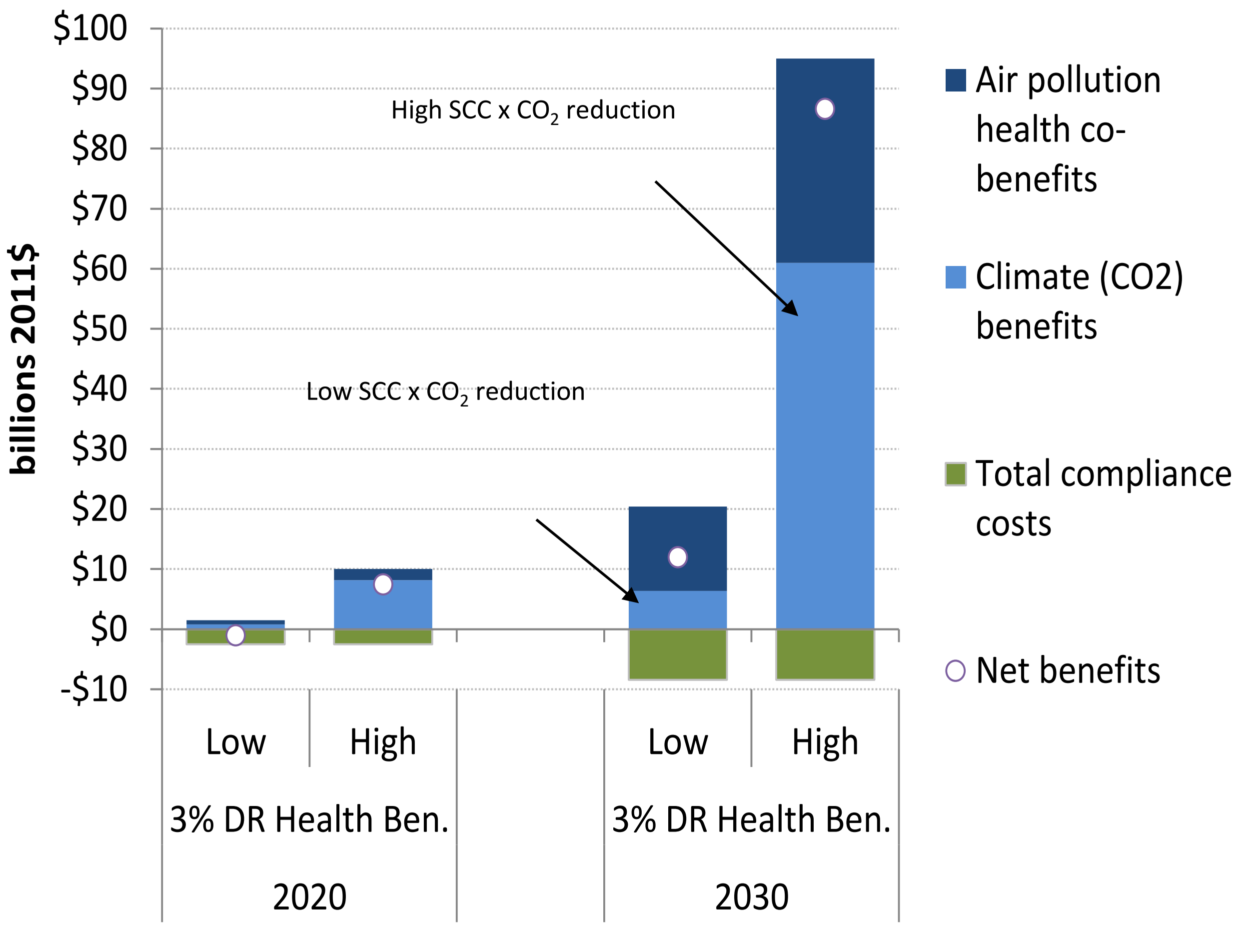
Discount Rate Year	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010	10	31	50	86
2015	11	36	56	105
2020	12	42	62	123
2025	14	46	68	138
2030	16	50	73	152
2035	18	55	78	168
2040	21	60	84	183
2045	23	64	89	197
2050	26	69	95	212

It is the U.S. Government's "central" SCC estimate of the future global damages to society from a metric ton of today's CO_2 emissions

Source: US Government (2015)

Why Should We Care?

- US Gov't uses SCC to estimate benefits of CO_2 reductions for federal rules
- US Gov't legally obligated to value CO_2
- SCC values updated in 2013 & 2015 significantly higher



Estimated 2020 and 2030 range of estimated benefits, costs, and net benefits for EPA's Clean Power Plan (Rate Based Approach)

SCC Used in Rulemaking, States and Other Countries

Types of impacts being monetized

Estimates based on sector specific impacts studies in the literature (incomplete & evolving)

- Health
- Agriculture
- Forestry
- Sea level
- Water resources
- Energy consumption (space cooling & heating)
- Migration
- Hurricanes
- Ecosystems
- Catastrophic









Types of Climate Impacts That Are Assessed Monetary Damages

What EPRI has Done to Date

1. Technical Assessment of SCC Modeling

– Very deep dive into modeling: deconstruction and diagnostic analyses of SCC modeling components and overall USG methodology

2. Analysis of SCC Application

– Analysis of implications of pricing power sector CO_2

3. Evaluation of Key Uncertainties

– Characterizing uncertainty about key modeling inputs

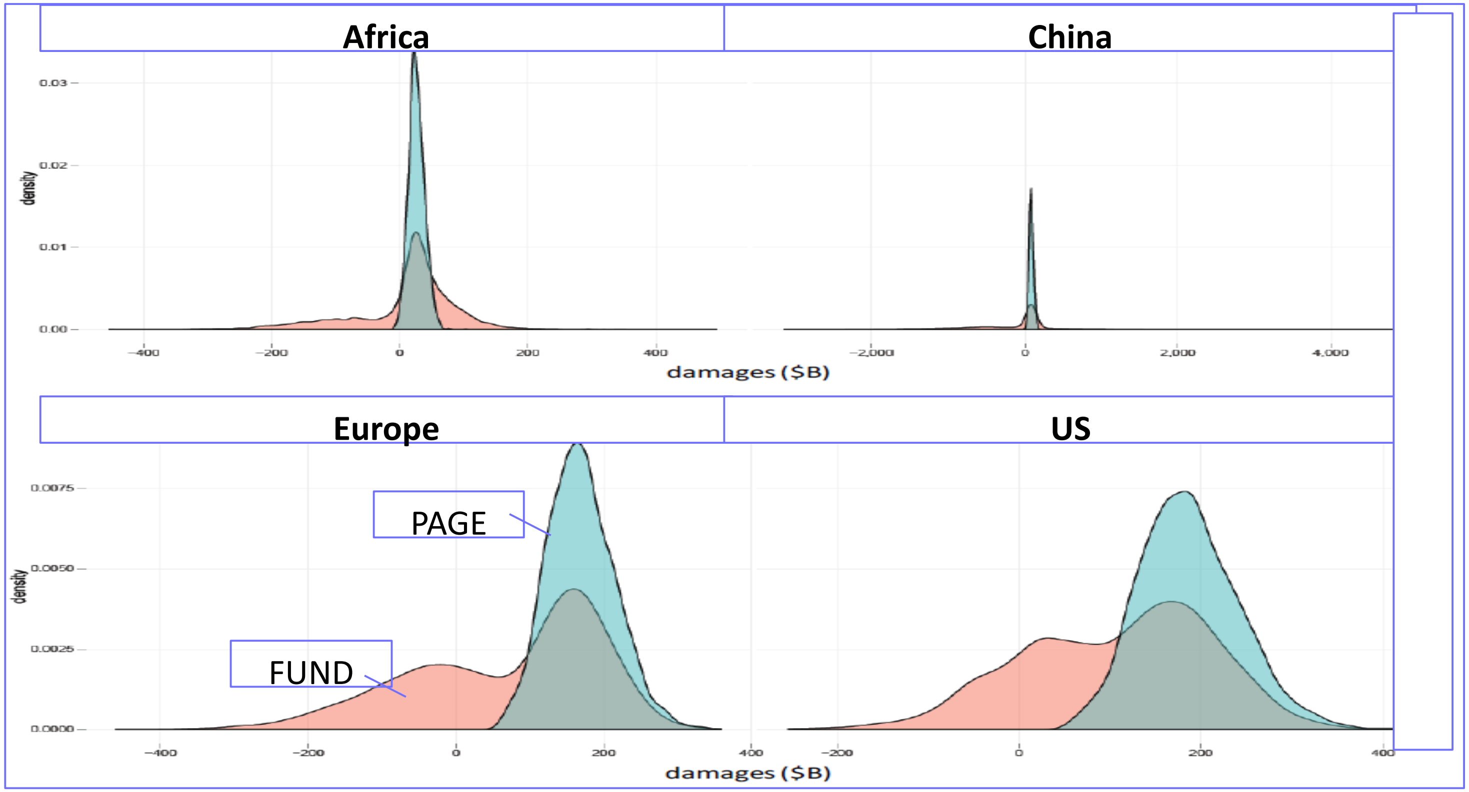
4. Provided Public SCC Comments

– OMB, EPA, and CEQ

– National Academy of Sciences

EPRI Proactively Provided Science-Based and Objective Public Comments

Future: Detailed Analyses Publication – Damages Uncertainty



Regional Climate Damage Distributions with 1.8˚C of Warming & USG2 Socioeconomics

Source: EPRI SCC Tech Assessment (2014)

EPRI Will Produce Detailed Report on Damage Uncertainty

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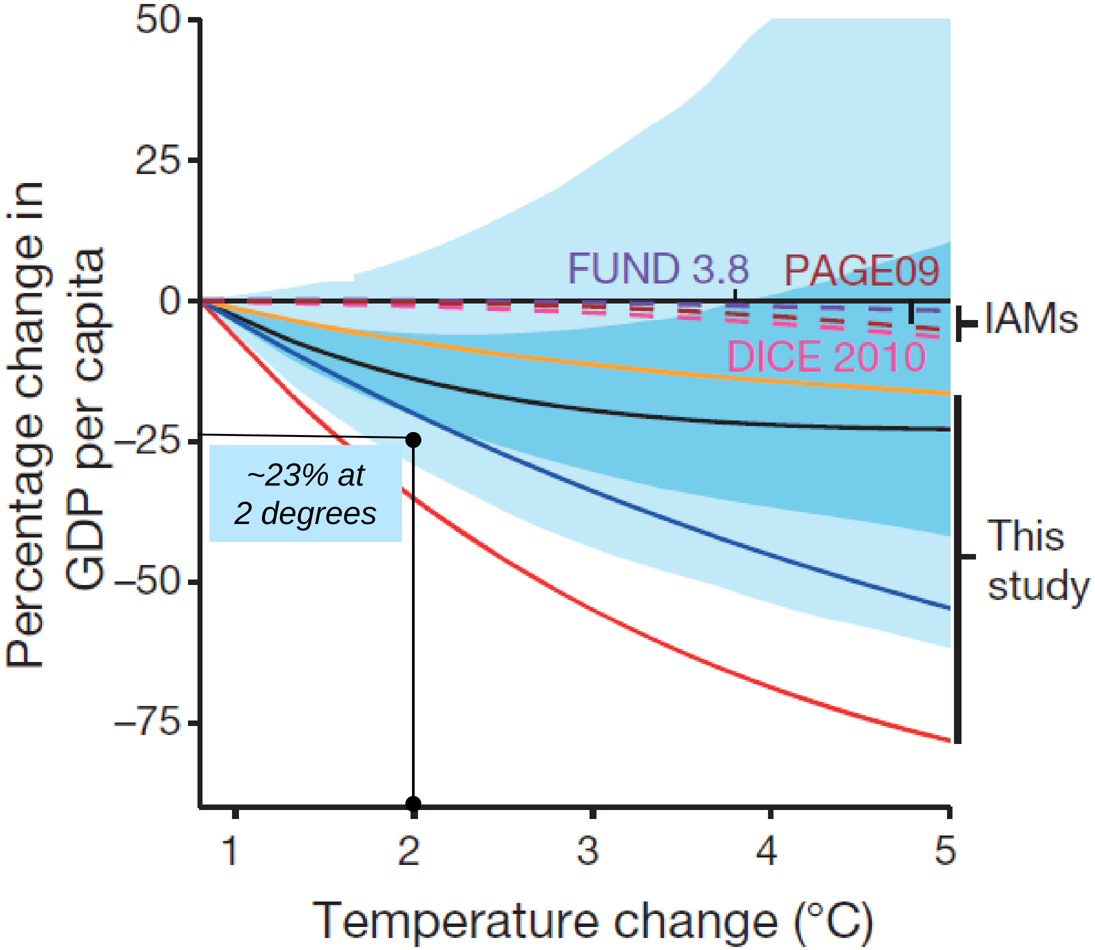
Future: Frontier Topics Review – Damages to Economic Growth

"If future adaptation mimics past adaptation, unmitigated warming is expected to reshape the global economy by **reducing average global incomes roughly 23% by 2100** and widening global income inequality" *(Burke et al., 2015)*



Source: Burke, Hsiang & Miguel (2015)

Next Discussion? Climate Impacts Vary with Global Economies

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Next Few Years are Important for SCC Review

- **National Academy of Science Review of Methodology and Approach**
- **US Gov't will revisit**
- **EPRI Work informs Discussion – expands beyond methodology with modeling impacts**

Next Few Years Are a Critical Window for Insights and Education

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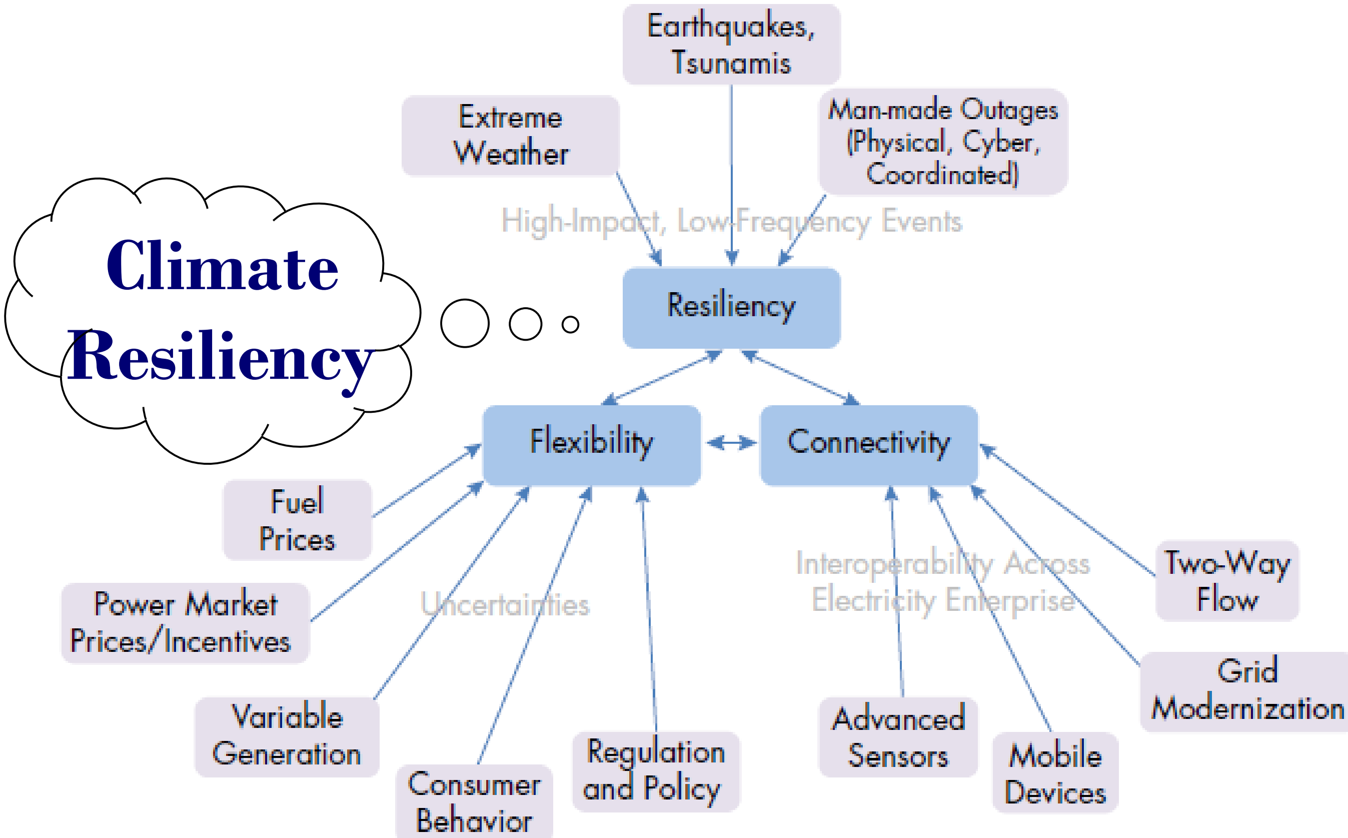
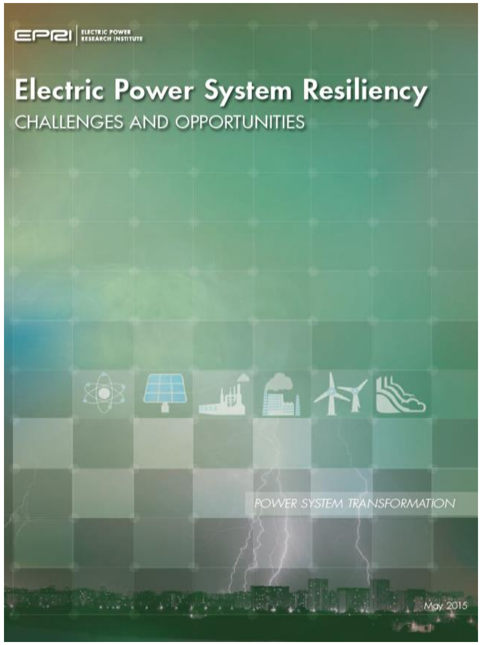
Power System Transformation: Flexibility, Resiliency and Connectivity White Papers

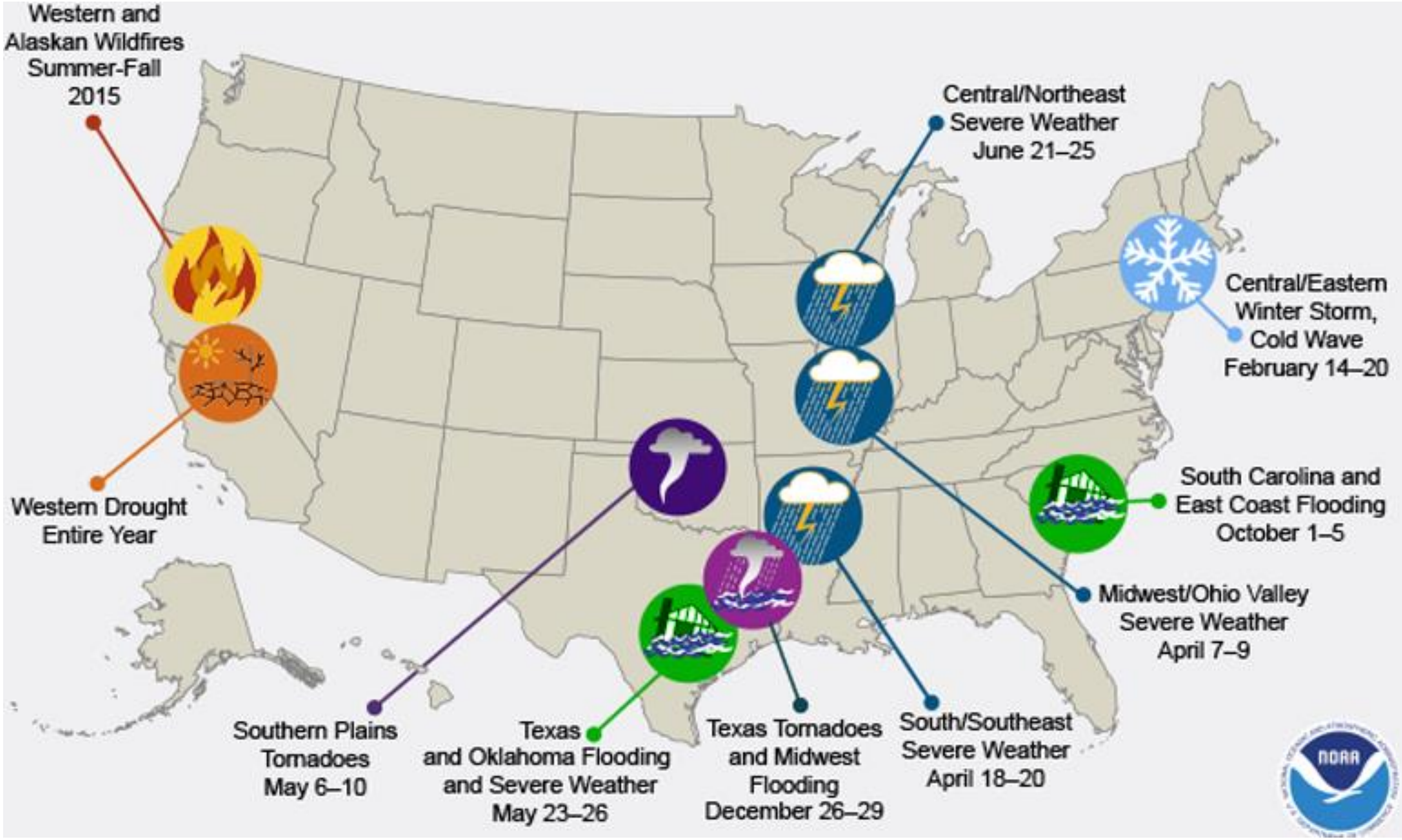




www.epri.com/Pages/Power-System-Transformation-White-Papers.aspx

EPRI Resiliency White Paper: Research Need in Metrics and Cost-Benefit

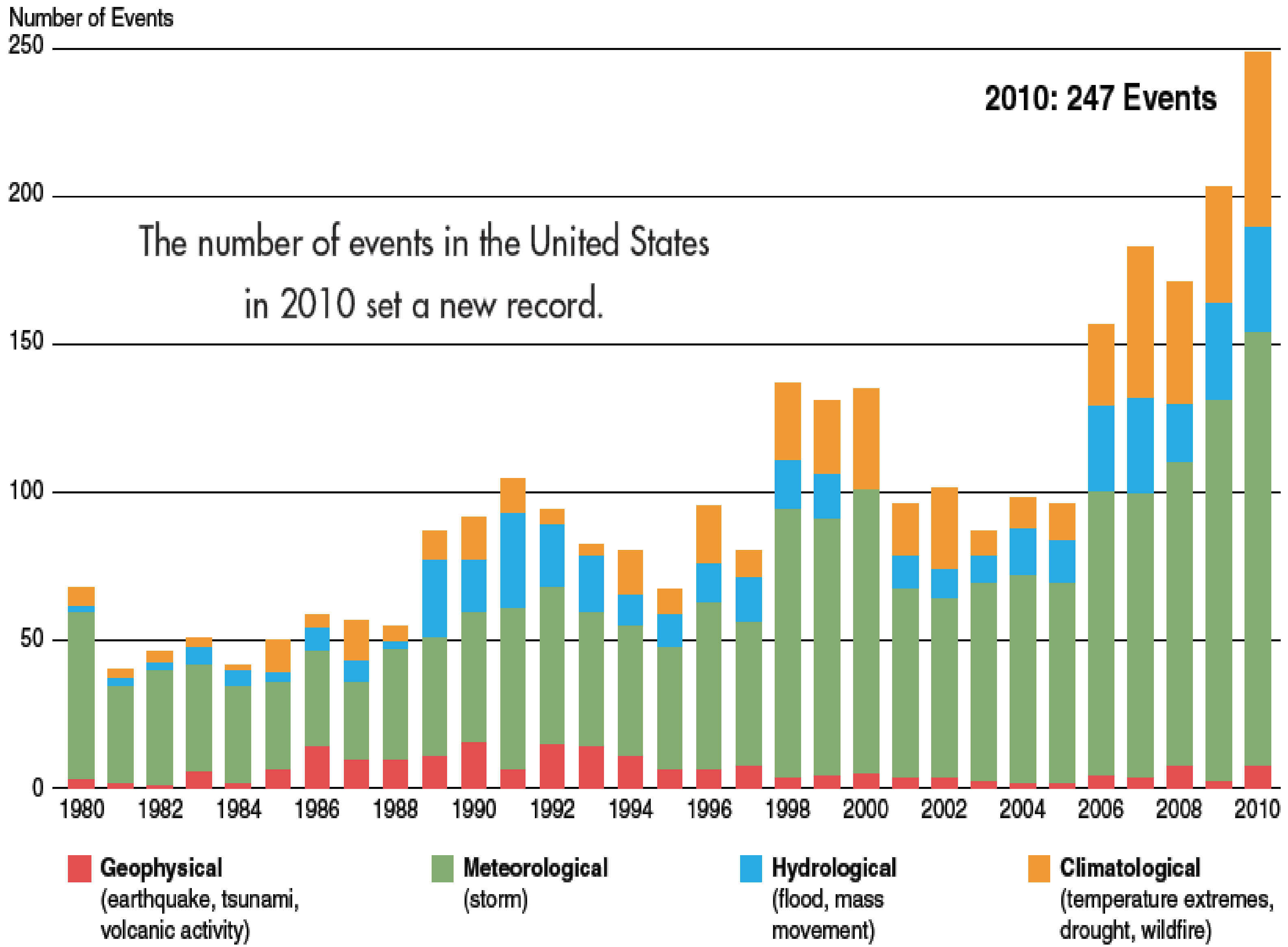
More Attention on Climate Resiliency and Econometrics



US 2015 Billion-Dollar Weather and Climate Disasters

Source: NOAA (2015)

Climate resiliency in the spotlight



NatCatSERVICE, Munich Reinsurance America (2011)

Role of "Climate Resiliency" Within Bigger Picture

(adapted from Figure 3 of Resiliency White Paper)

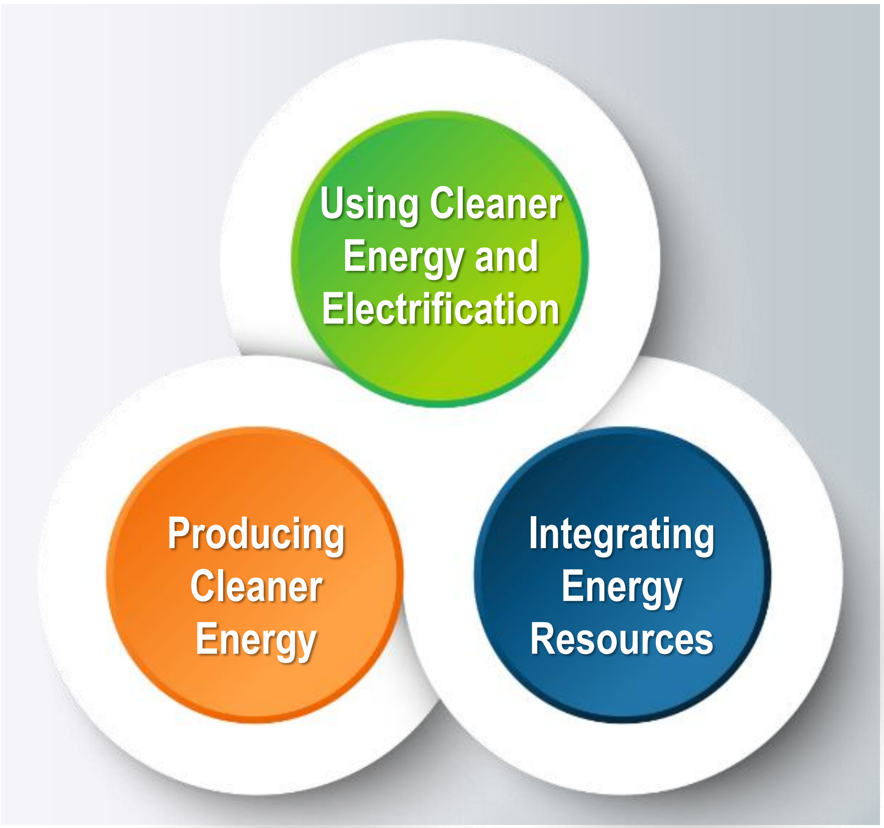
Resiliency

Damage Prevention (proactive)	**System Recovery (reactive)**	**Survivability (innovation & technology)**
Examples: Power Delivery & Utilization and Generation	Examples: Power Delivery & Utilization and Generation	Examples: Power Delivery & Utilization and Generation
HARDEN	RECOVER QUICKLY	ACCEPT

Climate Resiliency

Damage Prevention	System Recovery	Survivability
• Understand metrics • Risk management • Cost-benefit frameworks • Characterize threats	• Evaluate metrics • Damage assessment (economic) • Asset decision-making	• Economic and technical analysis) • Vulnerability assessments

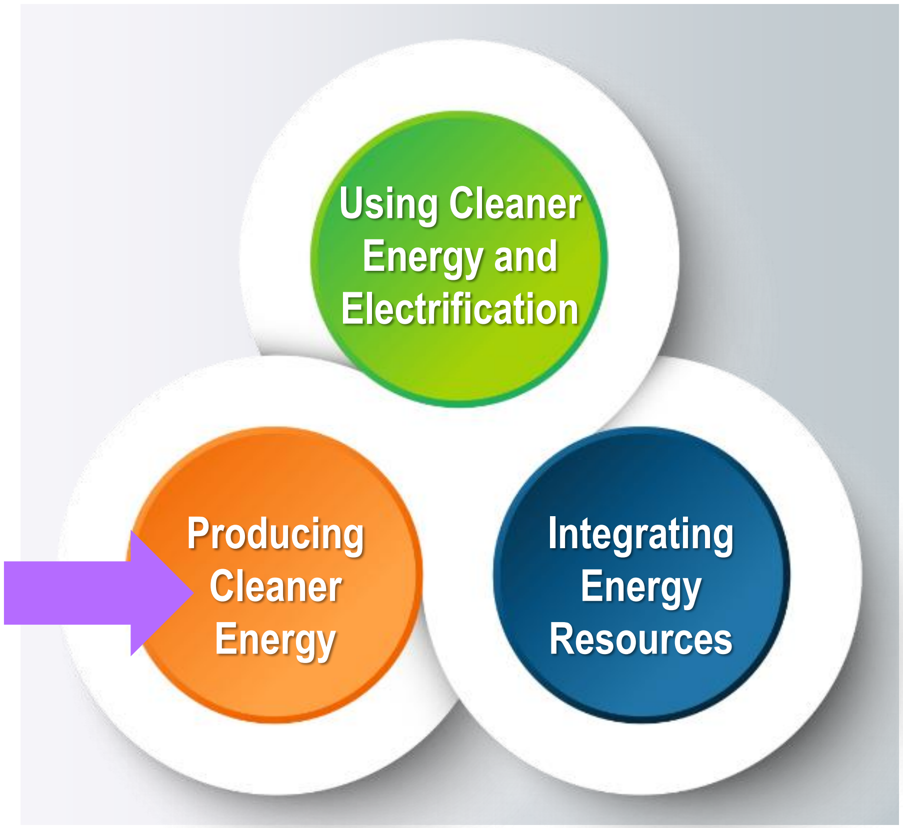
"Integrated Energy Network" - Three Evolving Infrastructures



"Integrated Energy Network"

A ***Network of Infrastructures that connects customers with clean energy production and use***

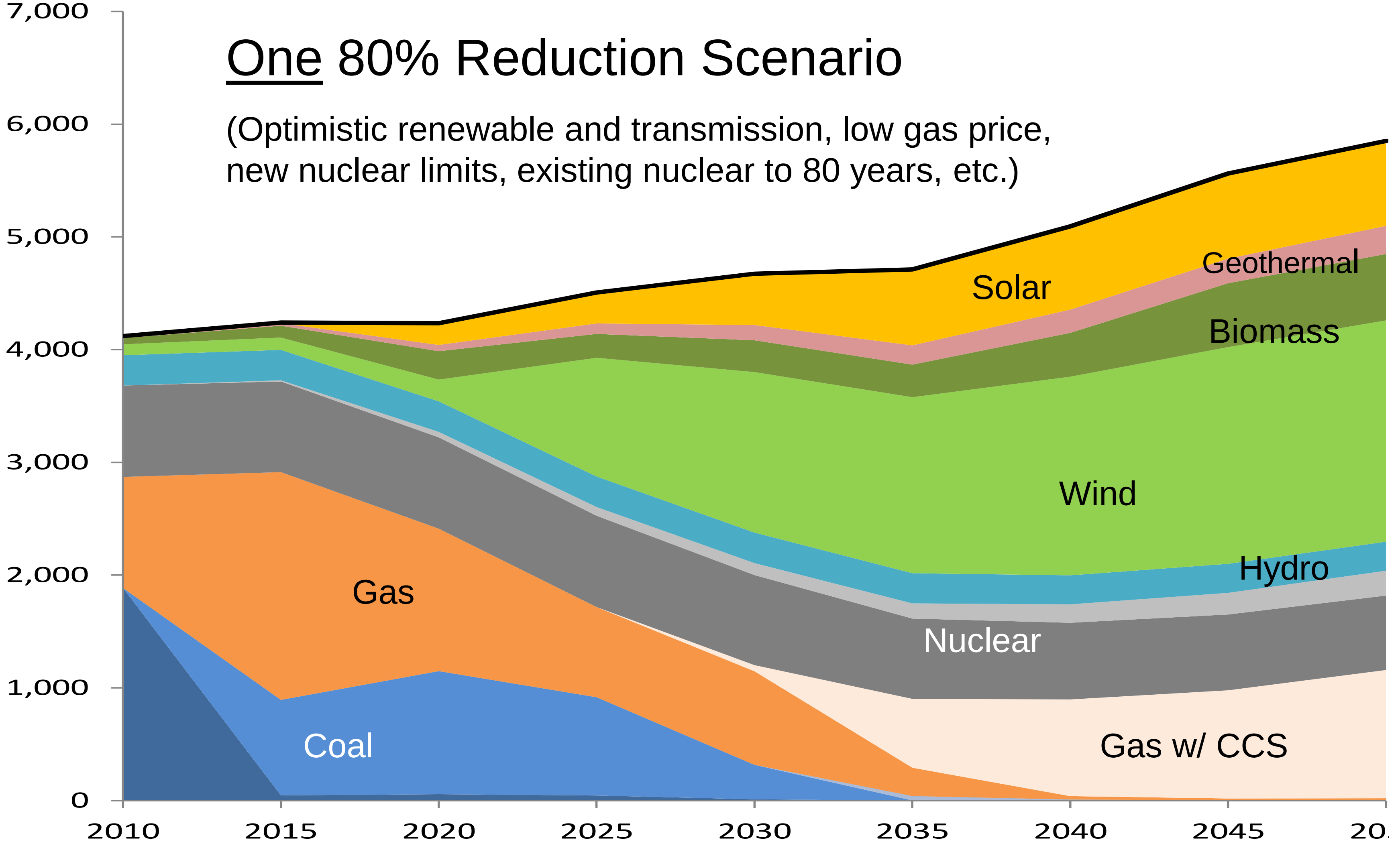
“Integrated Energy Network” - Three Evolving Infrastructures



“Integrated Energy Network”

A Network of Infrastructures that connects customers with clean energy production and use

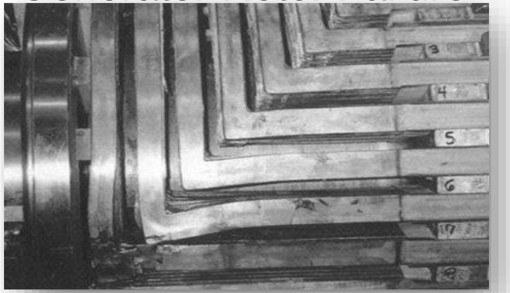
One Scenario Example: Coal & Gas Transition Fuels



Source: EPRI REGEN Model 2015 run

Flexible Generation Operations – Transition Strategy

Generator Rotor Failure



Corrosion Fatigue

Stress Cracking

Enabling a Changing Fossil Plant Mission…while managing risk

Operational Performance Improvements

- Advanced inspection, non-destructive evaluation and repair technologies
- O&M cost reductions aligned with unit mission, flexibility & reliability objectives
- Automated fleet-wide monitoring with advanced diagnostics

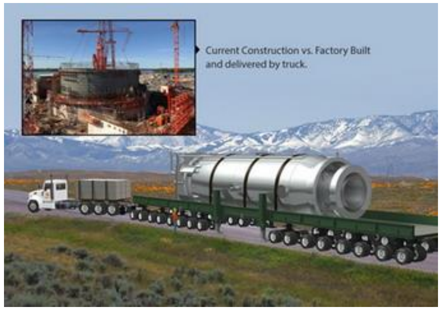
- Advanced Process Control
- Asset Monitoring and Diagnostics
- Data Integration and Information Management
- Sensors and Actuation

Improving operational fossil performance and economics

Current Landscape for Advanced Nuclear

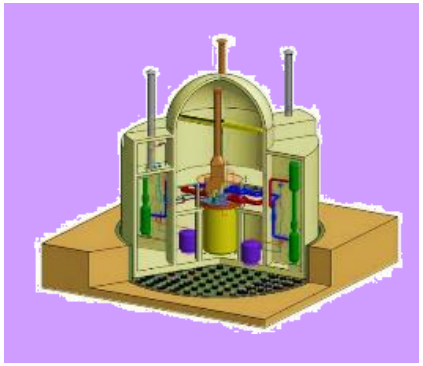
- Convergence of public and private interest in advanced nuclear over past two years
- Overt White House support, not seen since Eisenhower administration
- Growing Congressional interest and support
- NRC engagement and consideration of appropriate license approach
- 40-50 entrepreneurs with variants and applications at all scales
- >$1.5B private investor interest
- International collaboration growing

There is a bright future for nuclear energy



State-of-the-art transportation by water and air enables modularity on a different scale

Offshore Platform



GEN IV Nuclear

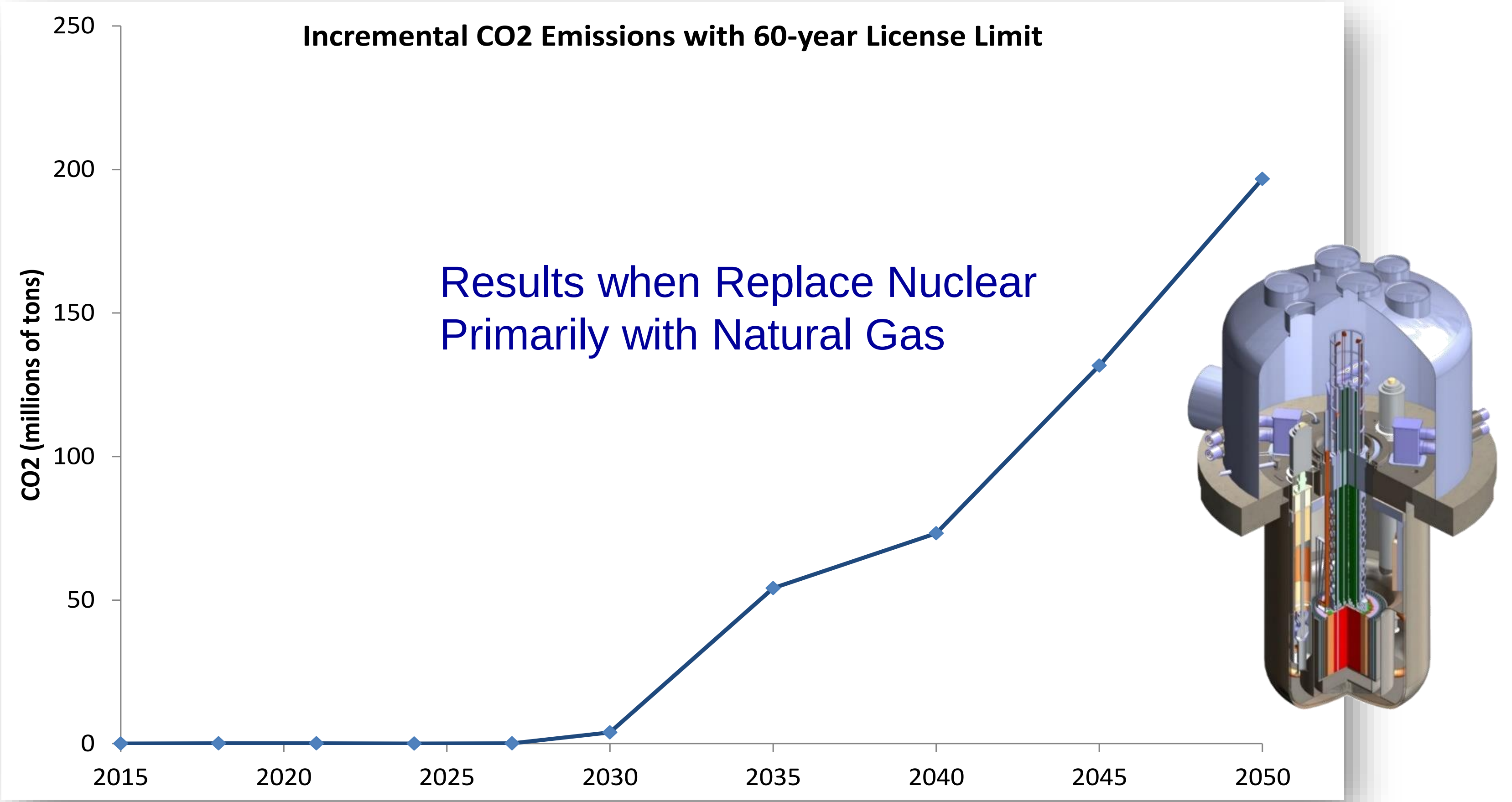
Small Modular Reactor

But…

Can the Future Come Fast Enough for Nuclear?

- **Current financial challenges**
  - Several shutdowns
- **Long lead time for licensing and construction**
  - NRC has made progress on Design Certification, Early Site Permits, Combined License applications, but only a few actively moving forward in US
- **Financing new projects is challenging**
- **Competition from low cost natural gas**
- **Expansion of renewables**

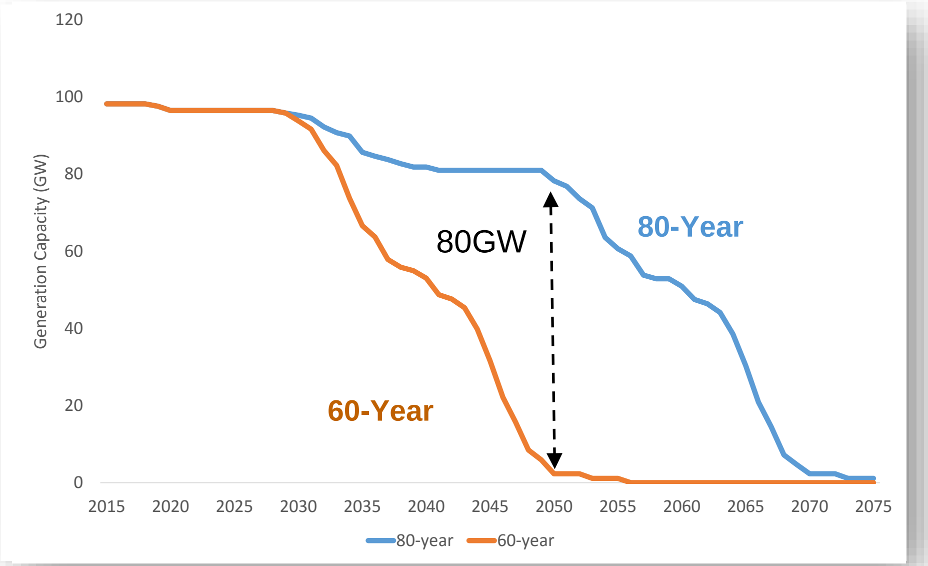
Replacing the U.S. Nuclear Fleet – Without Carbon Policy



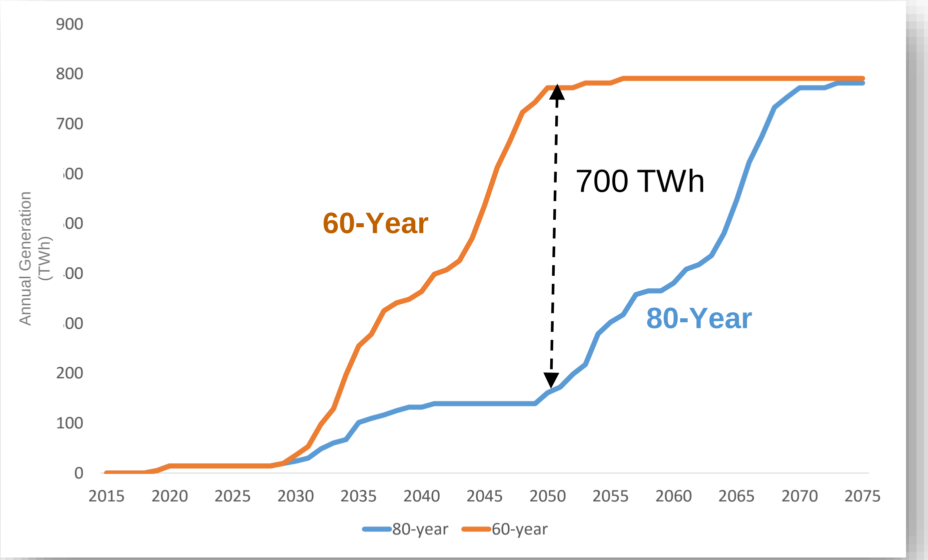
60-Year Nuclear License Limit: A 200 Million Ton Increase in CO_2 Emissions in 2050

Large Value in Extending Existing Nuclear Licenses in US

Capacity Gain – 80GW in 2050



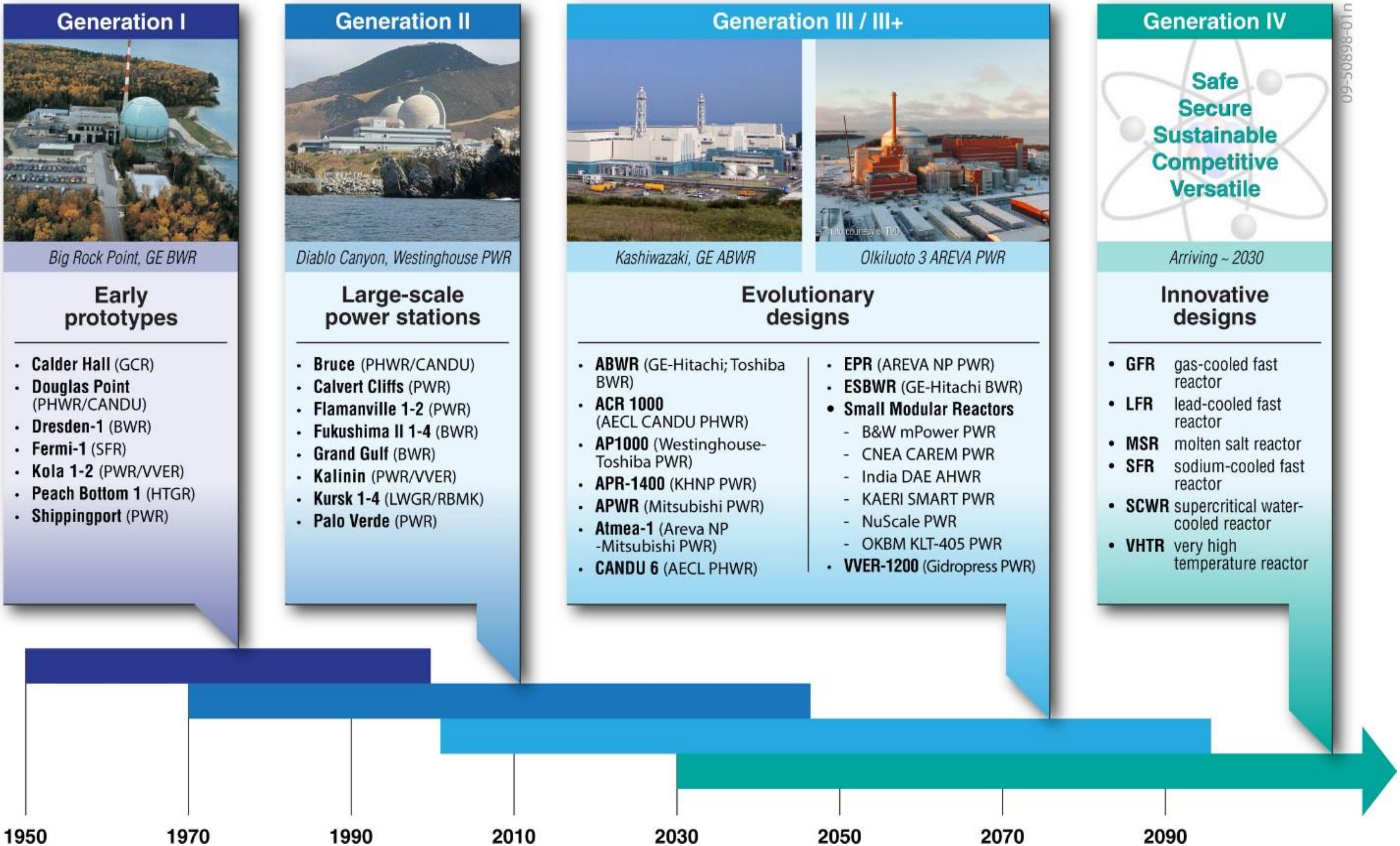
Energy Gain – 700 TWh in 2050



Note: Assumes 92% capacity factor for nuclear fleet

> $100 billion present value savings in an 80% 2050 GHG Reduction Scenario

What Is Advanced Nuclear?



"Advanced Nuclear" can encompass SMRs, GEN IV and Fusion

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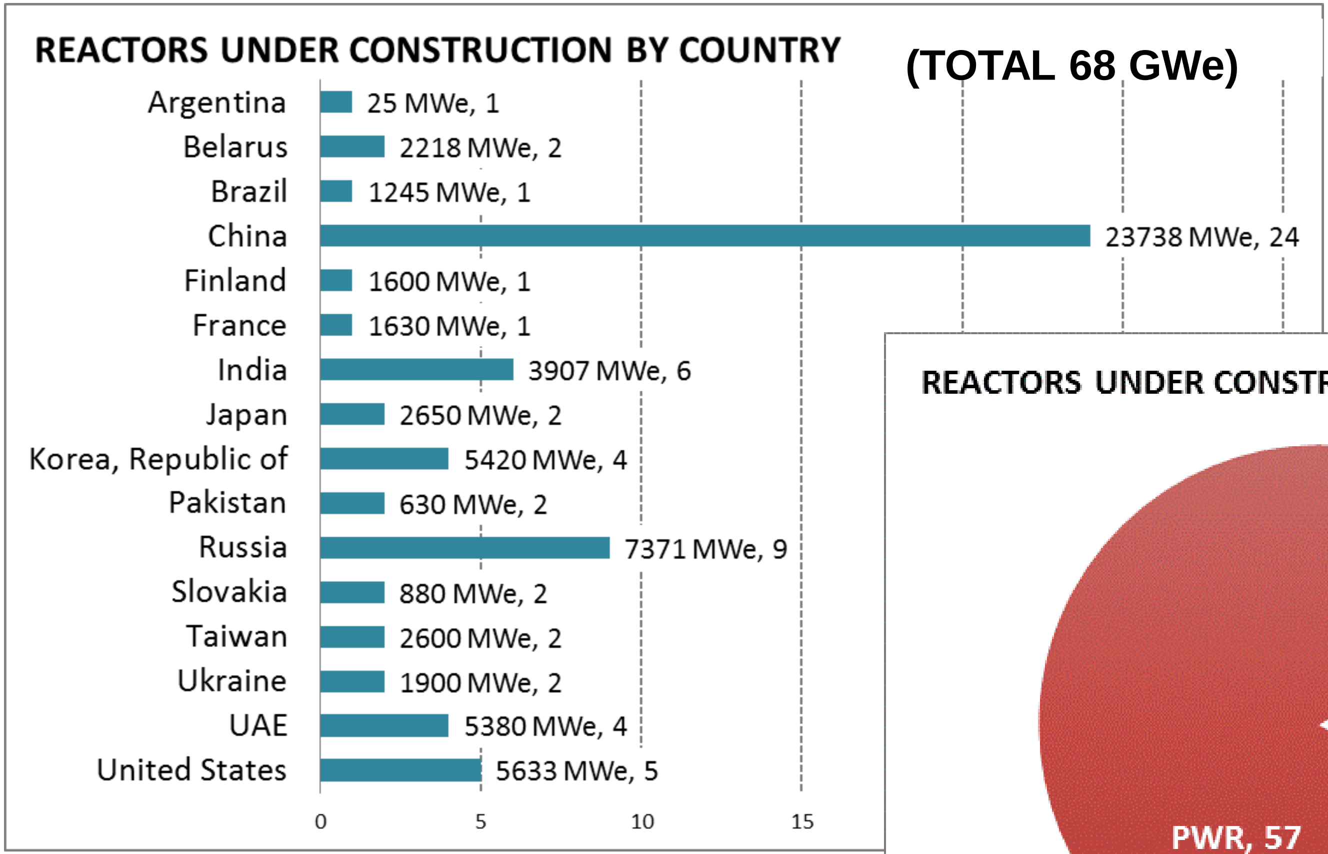
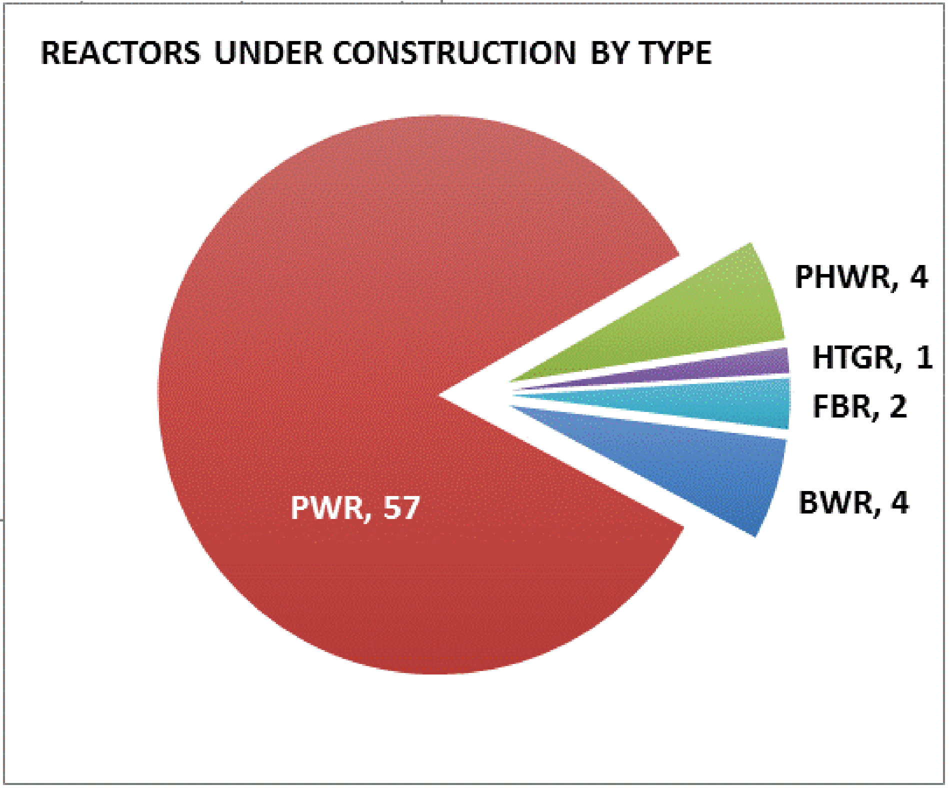
Robust International Market for New Build





Source: IAEA PRIS Database. Updated 29 Sept 2015

SMRs in the US

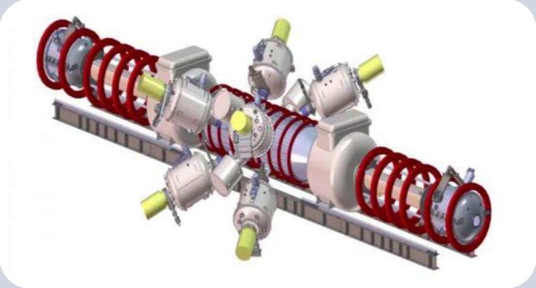
- NuScale, with DOE support is submitting design certification application this year
- TVA has recently submitted an Early Site Permit application – novel approaches
- Plans have been announced to build the first NuScale SMR in Idaho, owned by UAMPs and operated by Energy Northwest.

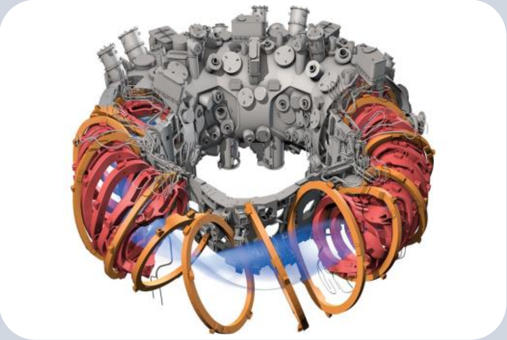
Light Water Based SMRs

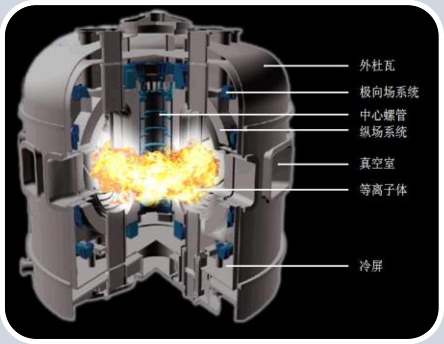
Developer/ Vendor	Design	Country of Origin	Type[a]	Electrical Output per Unit (MWe)	No. Under construction
Babcock & Wilcox	mPower	United States	iPWR	180	0
NuScale Power Inc.	NuScale	United States	iPWR	50	0
Westinghouse	W-SMR	United States	iPWR	225+	0
Holtec	SMR-160	United States	PWR[b]	160	0
CNNC	ACP100	China	PWR	100	0
CNEA	CAREM	Argentina	iPWR	25	1 (Argentina)
KAERI	SMART	South Korea	iPWR	100	0
OKBM Afrikantov	KLT-40S	Russia	PWR	35	2 (Russia)[c]
OKBM Afrikantov	VBER-300	Russia	PWR	325	0

[a] iPWR refers to integral pressurized water reactor design.
[b] Holtec considers its design to be an integral PWR; however, the steam generator and pressurizer are external to the reactor pressure vessel, directly connected (no piping) in an offset configuration.
[c] Twin-units deployed on a floating barge.

2015-2016 Fusion Milestones







Tri-Alpha Energy

- Sustained hydrogen plasma at 1 keV for 5 ms
- Novel reactor requires fewer magnets
- Most advanced privately-funded effort
- Only known reactor planning boron fusion

Wendelstein 7-X

- German stellarator uses very complex magnet design
- Helium plasma sustained for 100 ms at about 0.08 keV
- Uses superconducting magnets

EAST

- Chinese tokamak reactor operating since 2006
- Sustained hydrogen plasma at 4.3 keV for 102 seconds in February 2016
- Uses superconducting magnets

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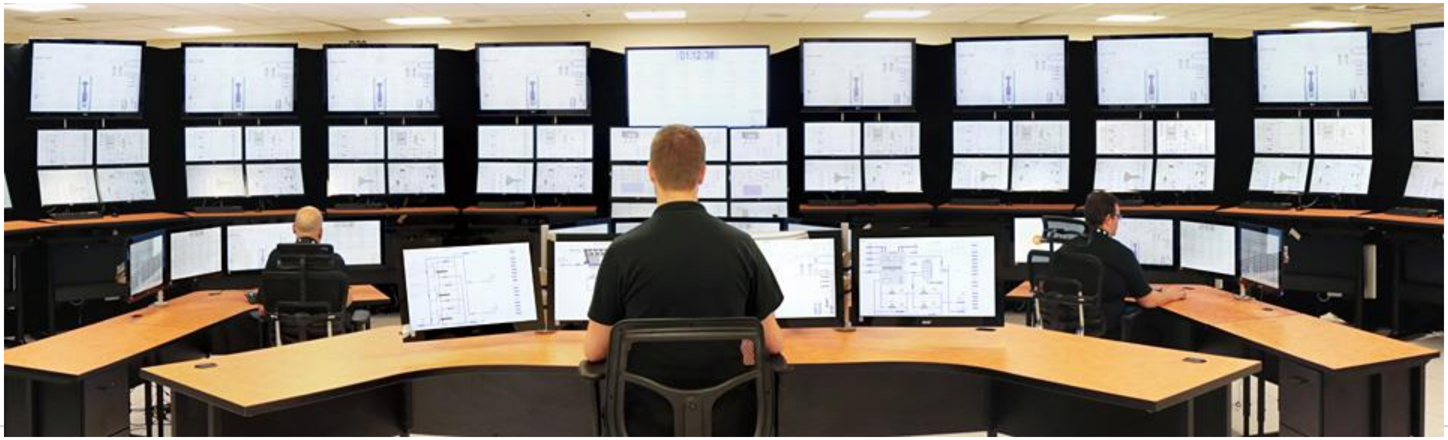
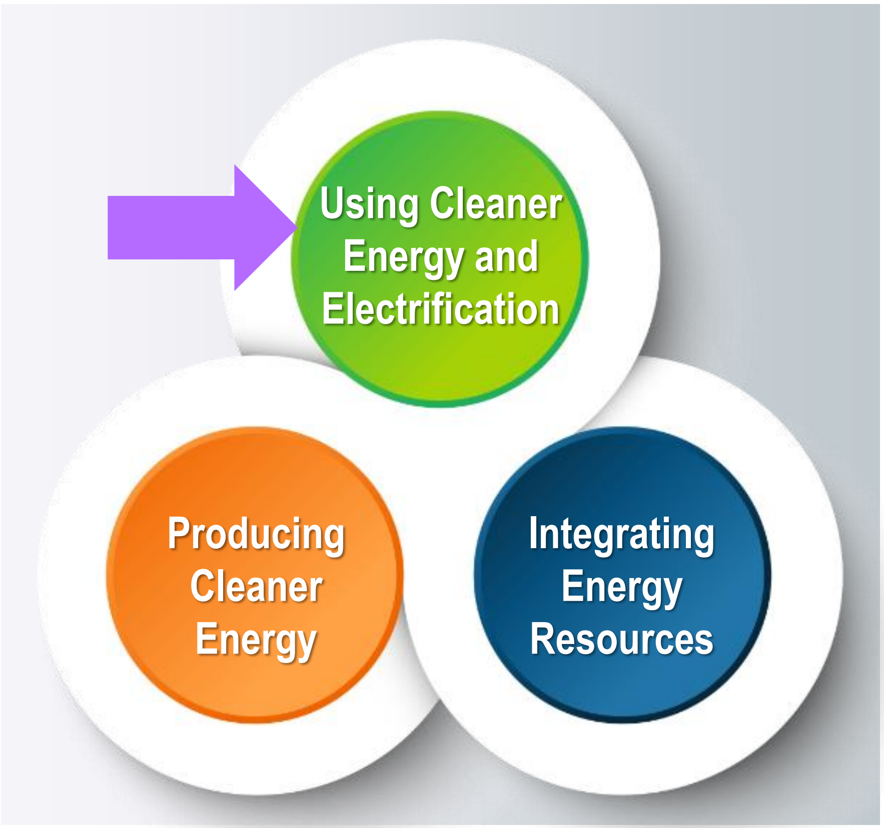
21^{st} Century Role for Advanced Reactors

- **No Generation IV without healthy Generation II/III**
  - loss of viable nuclear industry infrastructure not easily reversed
- **Sustained future will require more compelling business cases derived from advanced reactor attributes:**
  - high efficiency electricity generation and/or alternate products via high temperature operation
  - enhanced passive safety from inherent physical properties
  - Waste management, asset flexibility



“Integrated Energy Network” - Three Evolving Infrastructures



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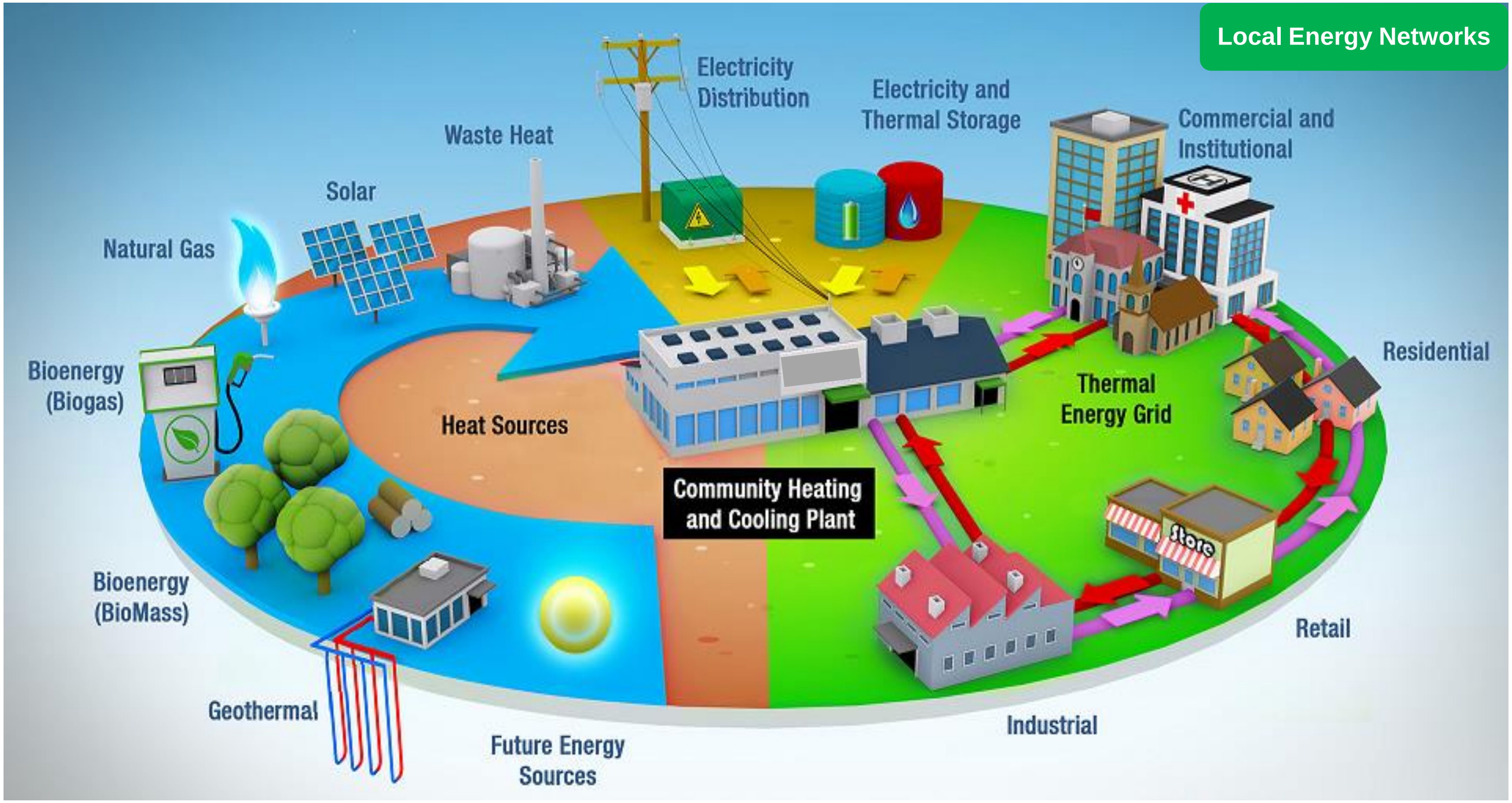
Example: Transition to Local Energy Networks

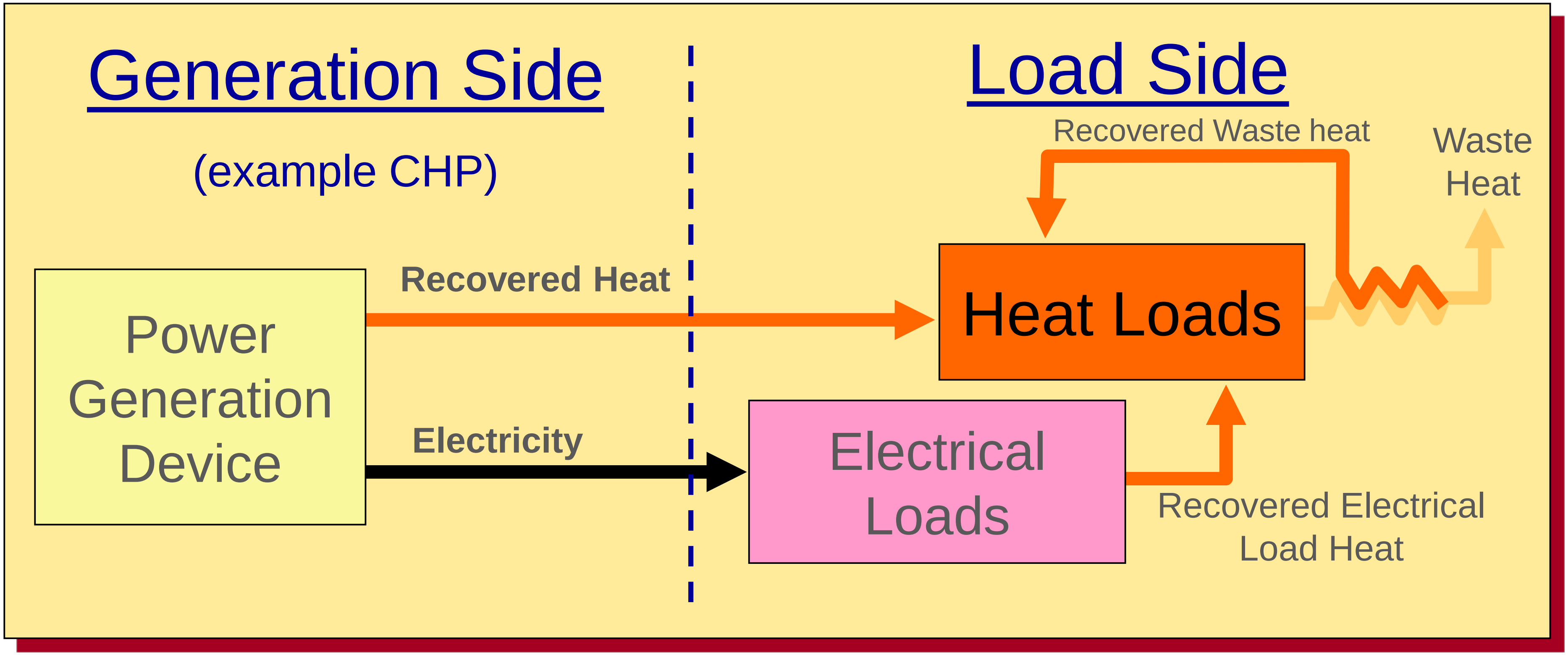


North America's First high-efficiency district energy network in Guelph, Ontario Canada

Source: Gupleh Hydro, Inc. an Envida Community Energy Jan. 2014

Heat-Recovery on the "Load-Side" Will Help Multi-Energy Economics

- Cogeneration or Combined Heat and Power (CHP) on the "generation side" is a well known way to improve efficiency – but there is much untapped heat that can be recovered on the "load-side" [see below]



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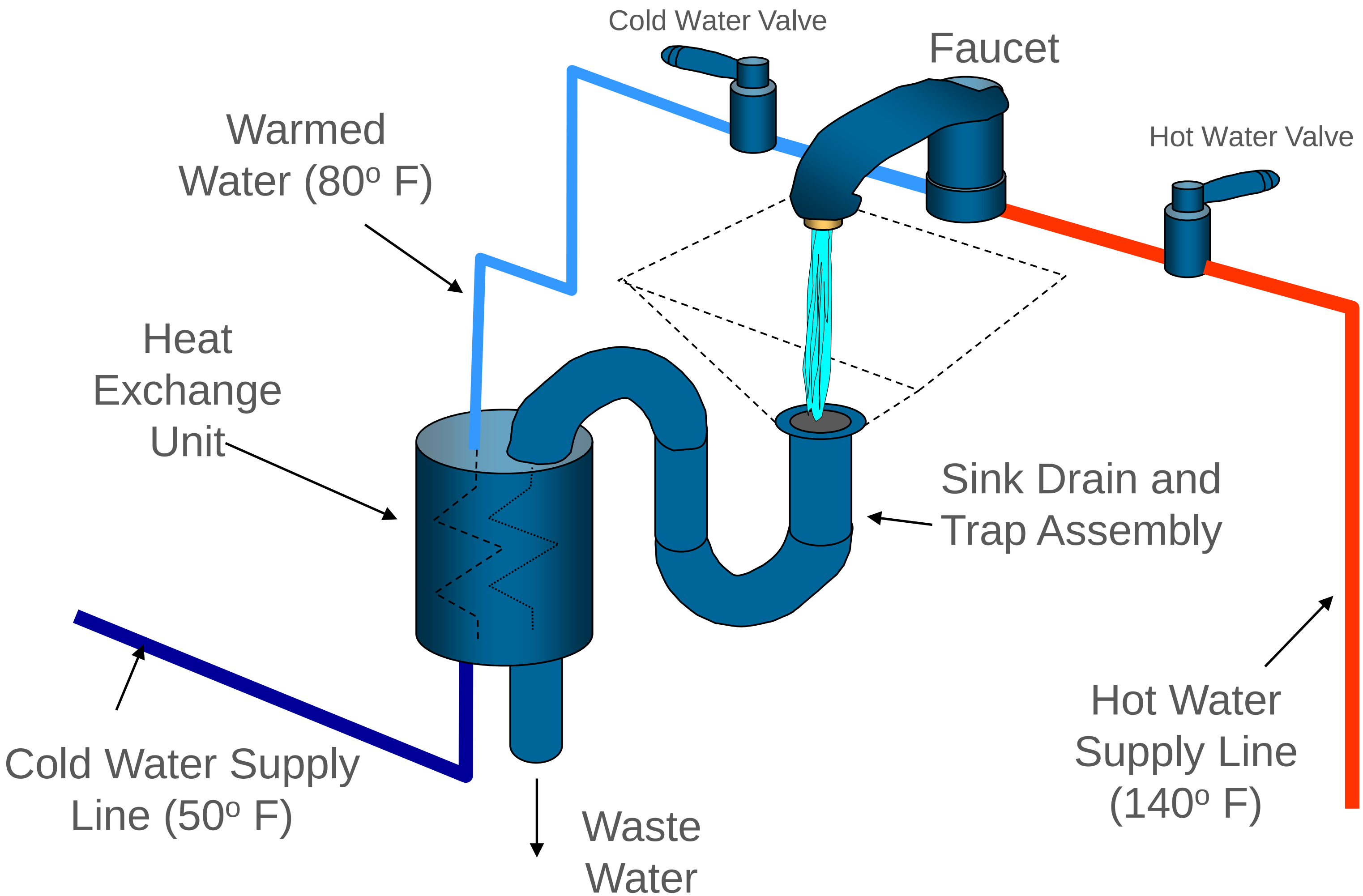
Example: *Air Conditioning Heat Exhaust Can be Recovered and Used!*

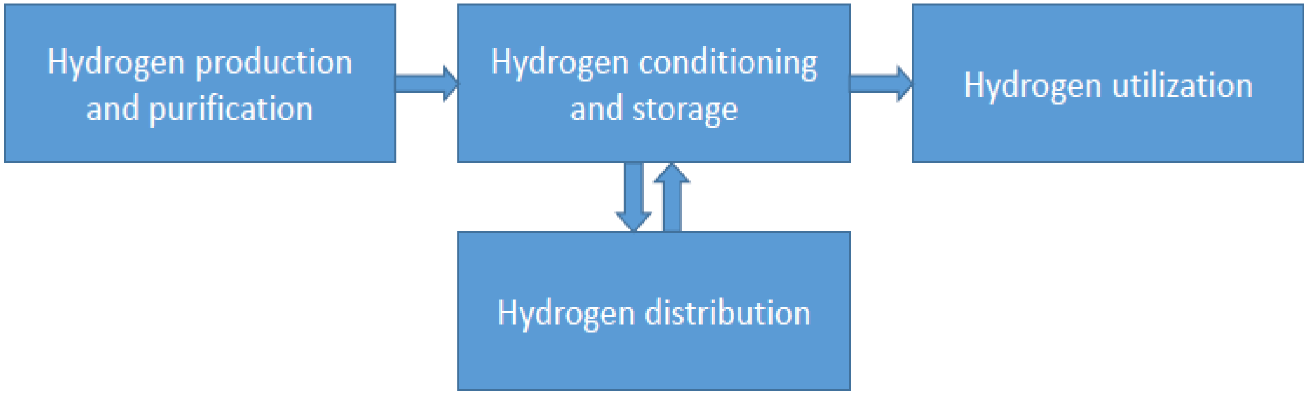
An air-conditioner unit that uses heat from the air-conditioning process to provide hot water!

Photo of Thermoplus Water Wise AC unit

Method to Recover Heat from Waste Water (sinks, showers, washers, etc.)



Hydrogen Economy



Hydrogen production and purification	Hydrogen conditioning and storage	Hydrogen distribution	Hydrogen utilization
Water electrolysis routes Reforming routes Gasification routes Innovative H_2 production H_2 purification	Compressed gaseous storage Liquefied storage Solid-state storage Long-term storage	Road, rail & sea H_2 pipelines Power-to-gas applications	Refueling stations Fuel Cells Fertilizer Hydrocracking

Philip Sharman, Evenlode Associates, Ltd, Berlin, Germany June 7-9, 2016

Hydrogen is a Flexible Energy Carrier

Production Methods

- **Chemical Processes**
  - Steam-Methane Reforming; Gasification; Solar/Nuclear Water Splitting
- **Electrolysis of Water**
- **Renewable Energy**
- **Biological**

Uses

- **Electricity**
  - Fuel Cells / Micro-CHP
  - Gas Turbines
  - Energy Storage
- **Transportation**
- **Chemicals**
  - Oil Refining, Methanol, Ammonia, etc.

Technical Characteristics

- 1 kg H_2 contains 33.3 kW of energy; 1 gallon of gasoline contains 33.4 kW
- H_2 has ¼ the energy density of gasoline
- \$2/kg H_2 is equivalent to \$17.60/MMBtu; Retail residential natural gas price is ~\$10.25/MMBtu

Combining low-Carbon emitting electricity with H2 production offers flexibility through storage

Transportation Commercially Available H_2-Fueled Cars

2016 Hyundai Tucson

5-year Lease Only: $499/month
(unlimited complimentary fuel included)
$2,999 at signing

2016 Toyota Mirai
MSRP: from $57,500
A 36-month lease for $499/month
(unlimited complimentary fuel included)
$3,649 due at signing

Commercially cars becoming available, though in select areas and at high cost

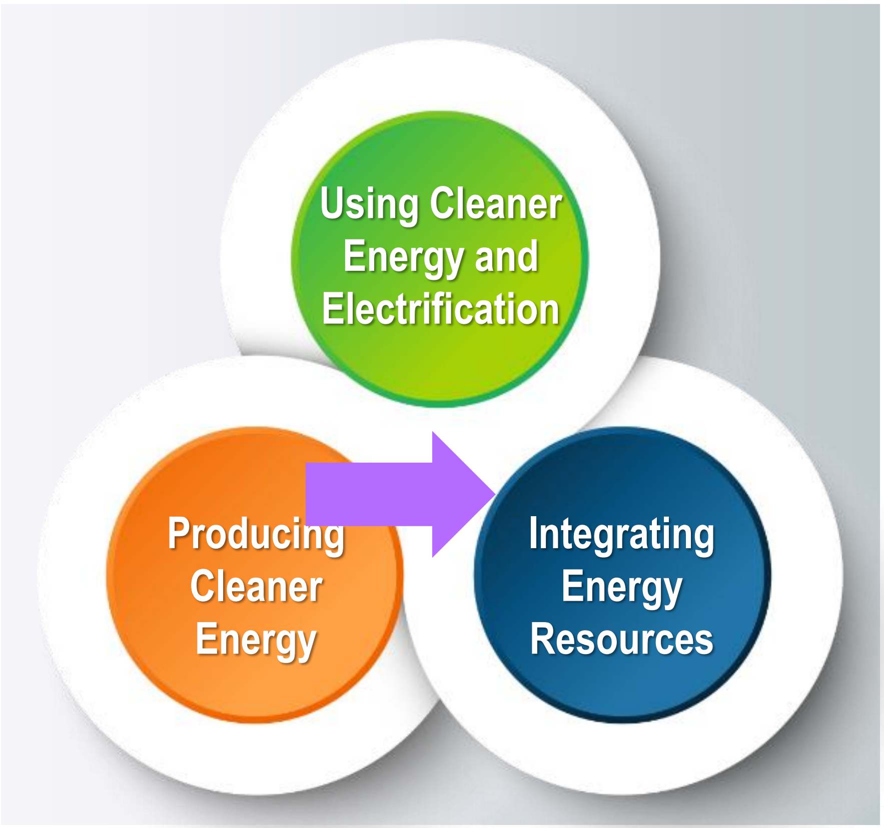
Key Insights – Hydrogen Technology

Water Electrolysis: $H_2O \rightarrow H_2 + ½O_2$

Hydrogen Production	H_2 Transport & Storage	Fuel Cells/Micro-CHP
• Steam-methane reforming is the most common technology at scale • PEM Electrolysis systems are viewed as the next best option • Advanced technologies such as water splitting using waste heat from solar or nuclear energy are in development • Integration of H_2 production with variable renewable energy offers opportunity	• Storage and truck/rail transport as pressurized gas or cryogenic liquid is commonplace, though low volume • <5,000 km of H_2 pipelines exist around the world • Potential to blend H_2 into existing natural gas pipelines is limited due to design limitations on the pipeline, compression and end-use equipment	• Natural gas-fueled systems for small commercial and industrial applications are fairly common • Japan and South Korea are leaders in deployment of residential micro-CHP systems • Improvements in component and system design are needed to support improved performance, life of the system, and economics

H_2 technologies are beginning to deploy in larger quantities, resulting in steady cost reductions

"Integrated Energy Network" - Three Evolving Infrastructures



"Integrated Energy Network"

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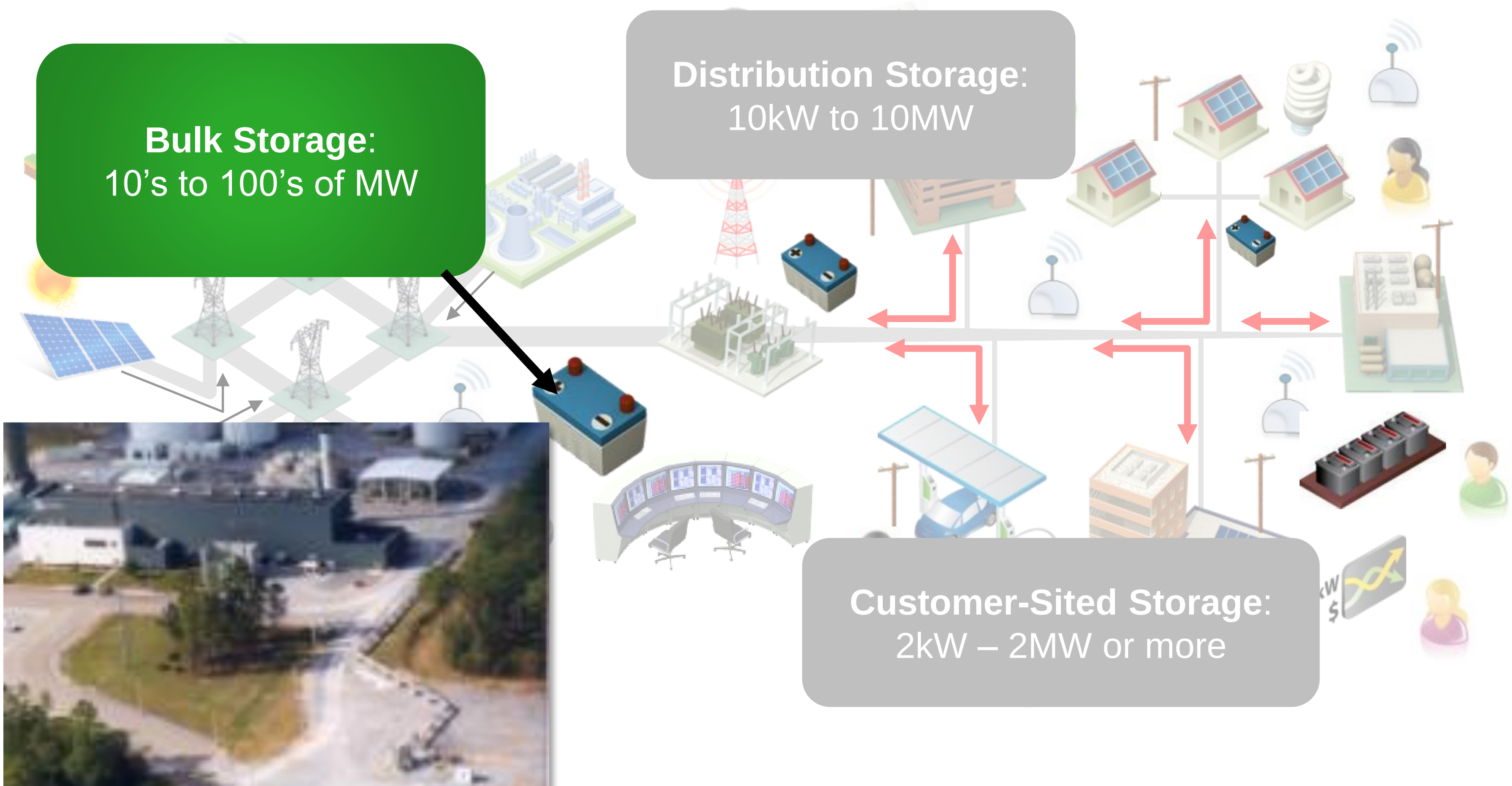
The "Answer" for Renewable Energy Intermittency?

Rendering of bulk energy storage system

Example #1: Bulk Energy Storage



MacIntosh Alabama Compressed Air Storage Plant

Centralized plants may support bulk system planning and operations

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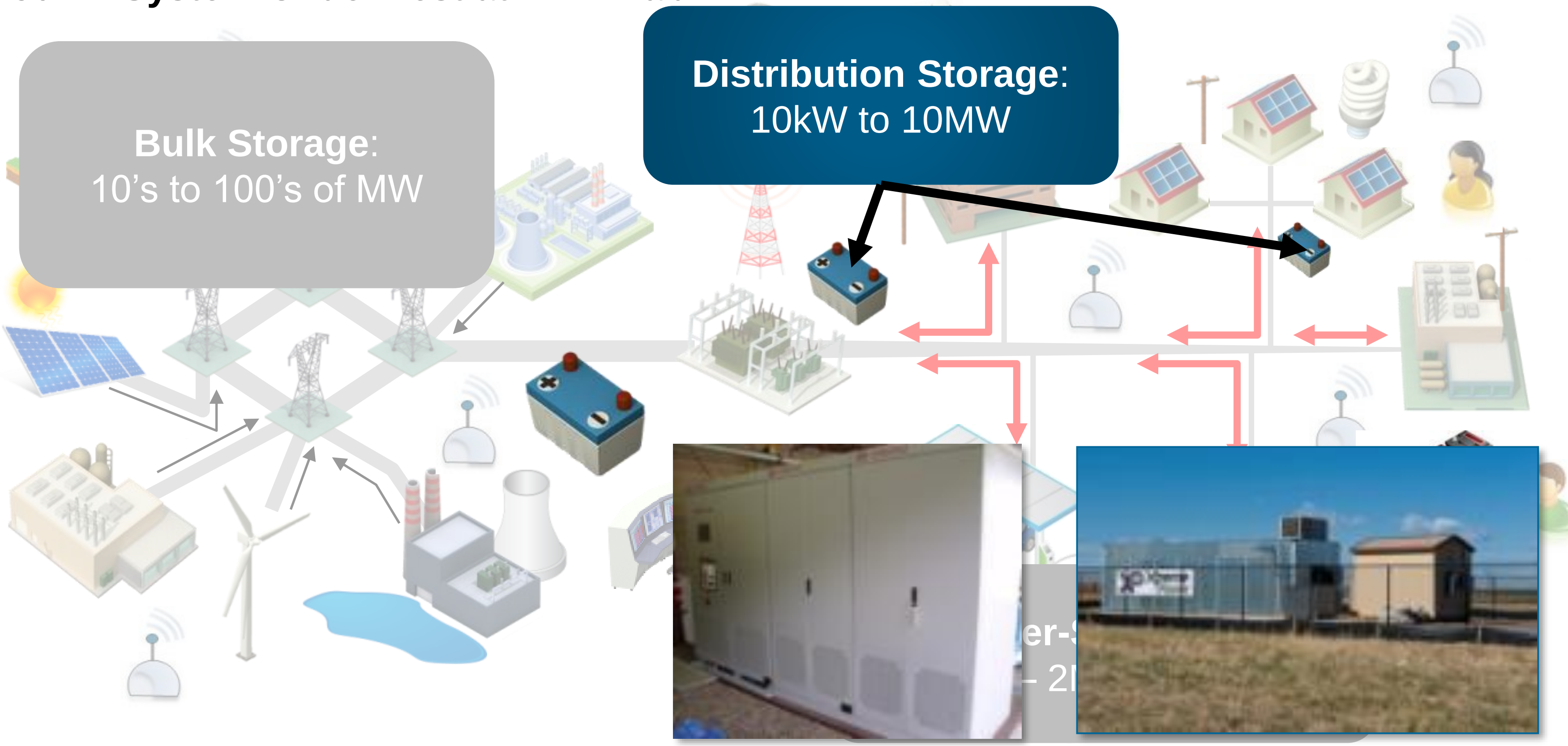
Example #2: Energy Storage – Distribution

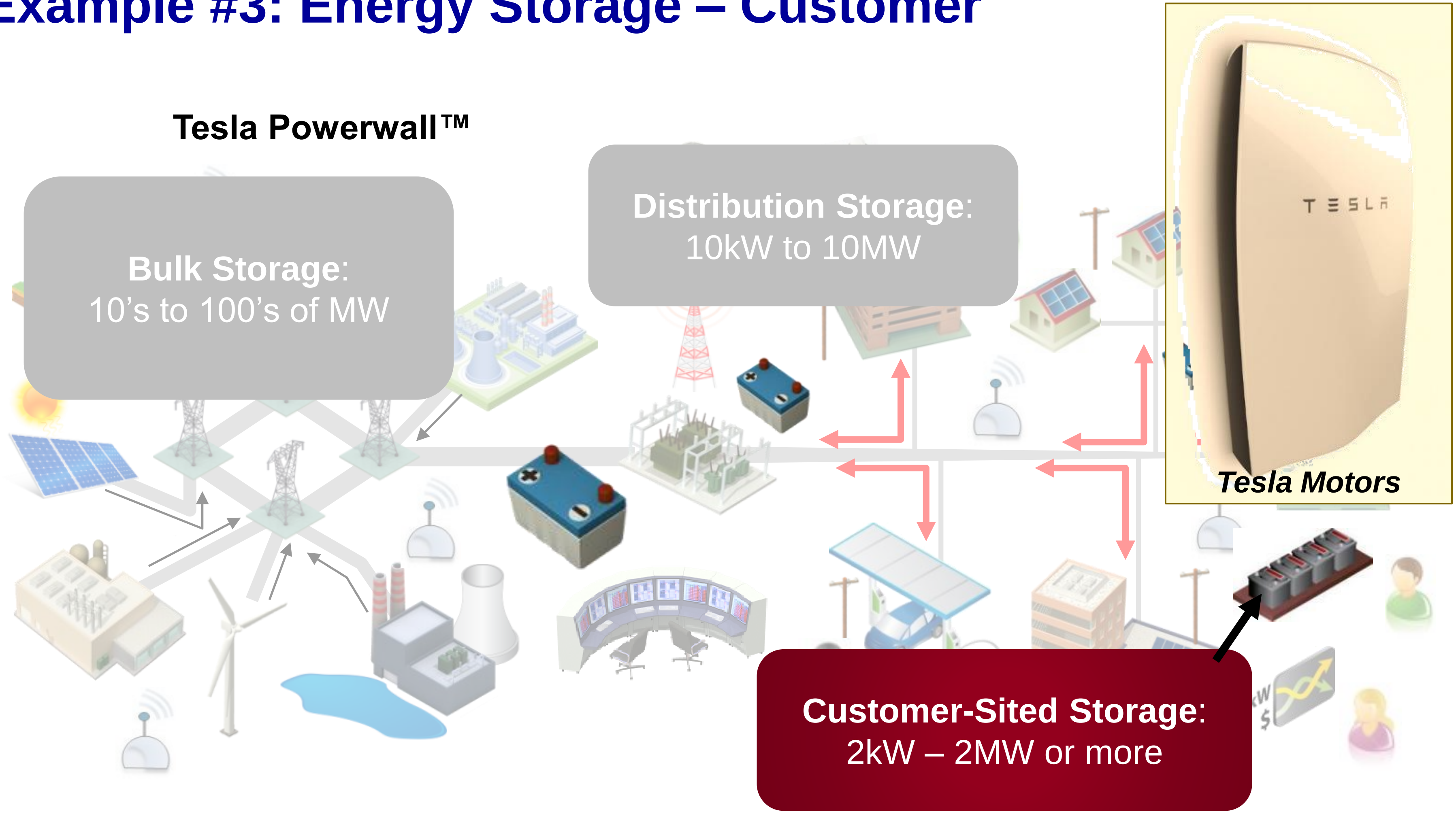
50kW System Under Test at EPRI Lab



500kW System Demonstration Outside Denver

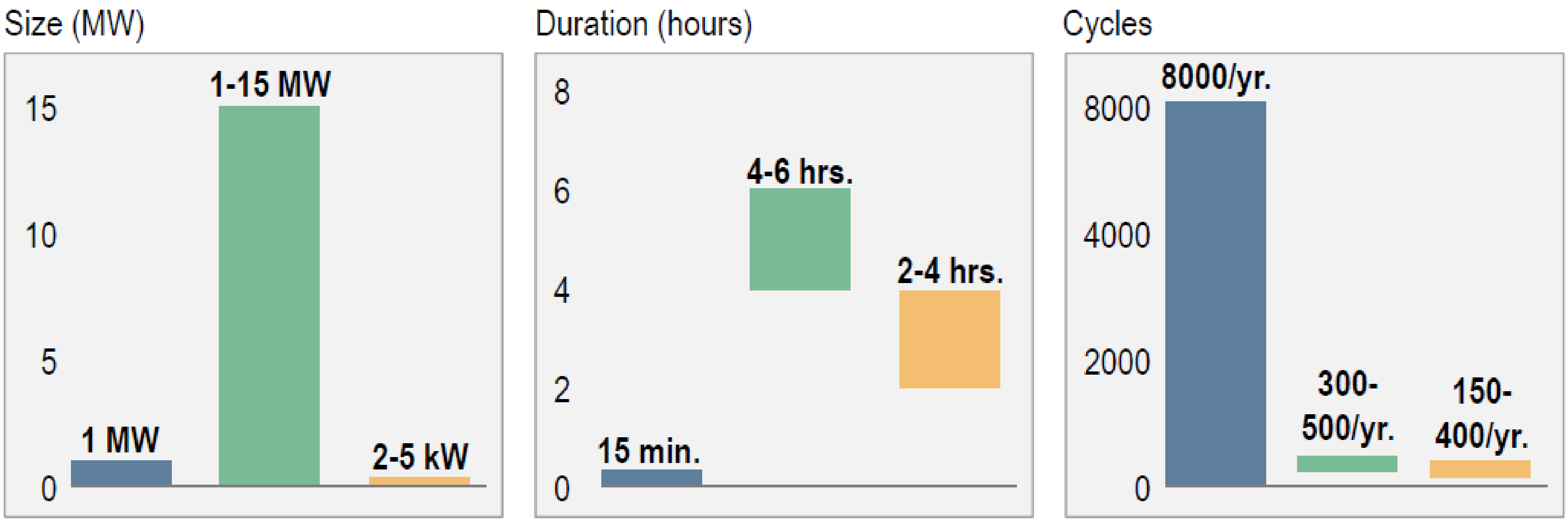
Modular systems could defer distribution investment and enhance local resiliency, while providing bulk benefits

Example #3: Energy Storage – Customer



Utility customers may adopt for bill savings, reliability, Potential demand response or grid service payments

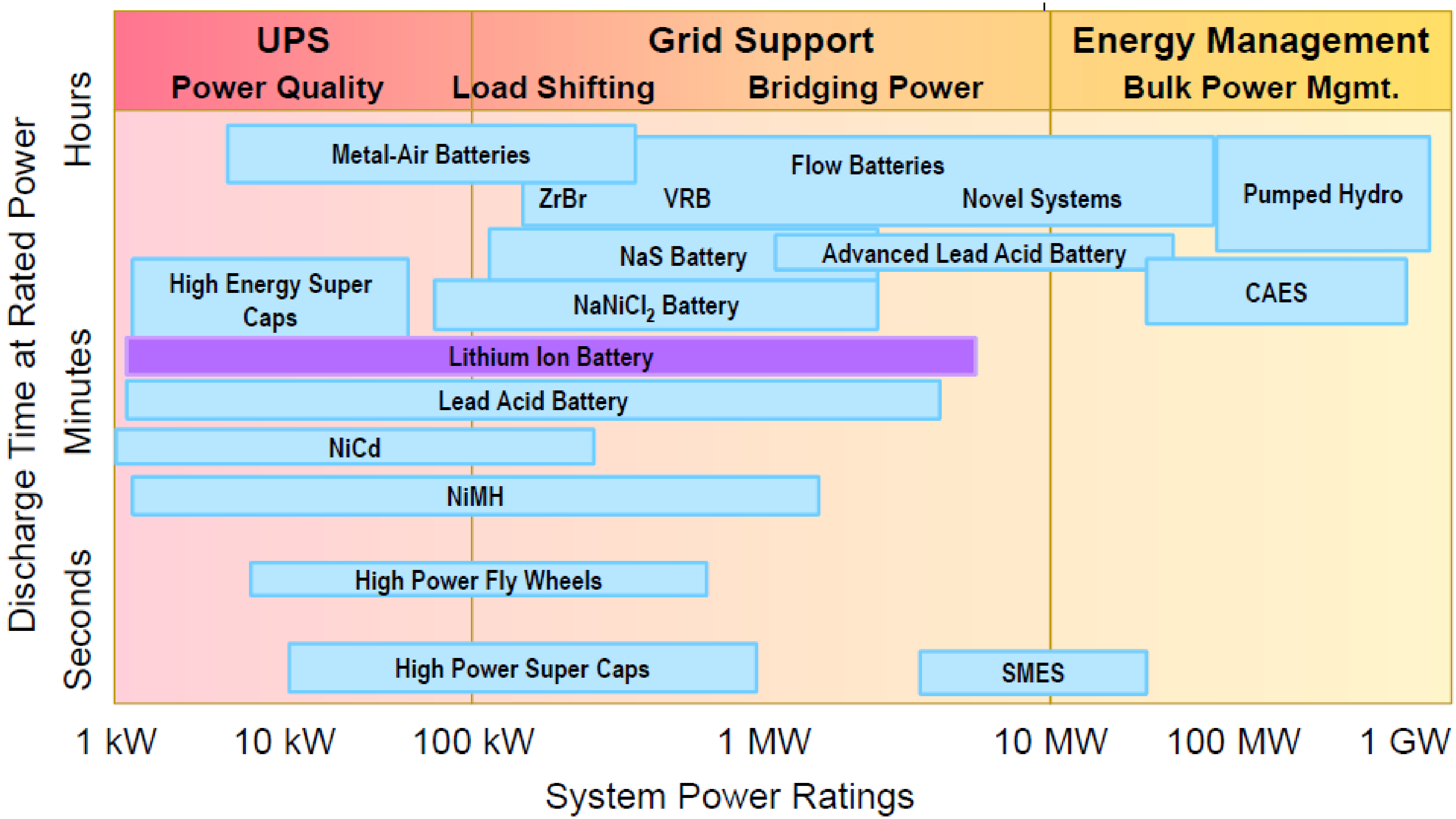
Energy Storage Characteristics for Various Applications



System Applications	*Wholesale Markets* Frequency regulation
Utility Applications	*T&D Support* Urban and rural distribution deferral, both stationary and transportable.
Residential Applications	*Home Energy Management, Distributed PV* Home energy management, back-up power, reliability

Key determinants for various applications: Peak power rating, number of hours of storage and cycling ability

Energy Storage Options –
Power Rating Versus Discharge Duration



Lithium ion battery technology will be the dominant technology for stationary application in the foreseeable future

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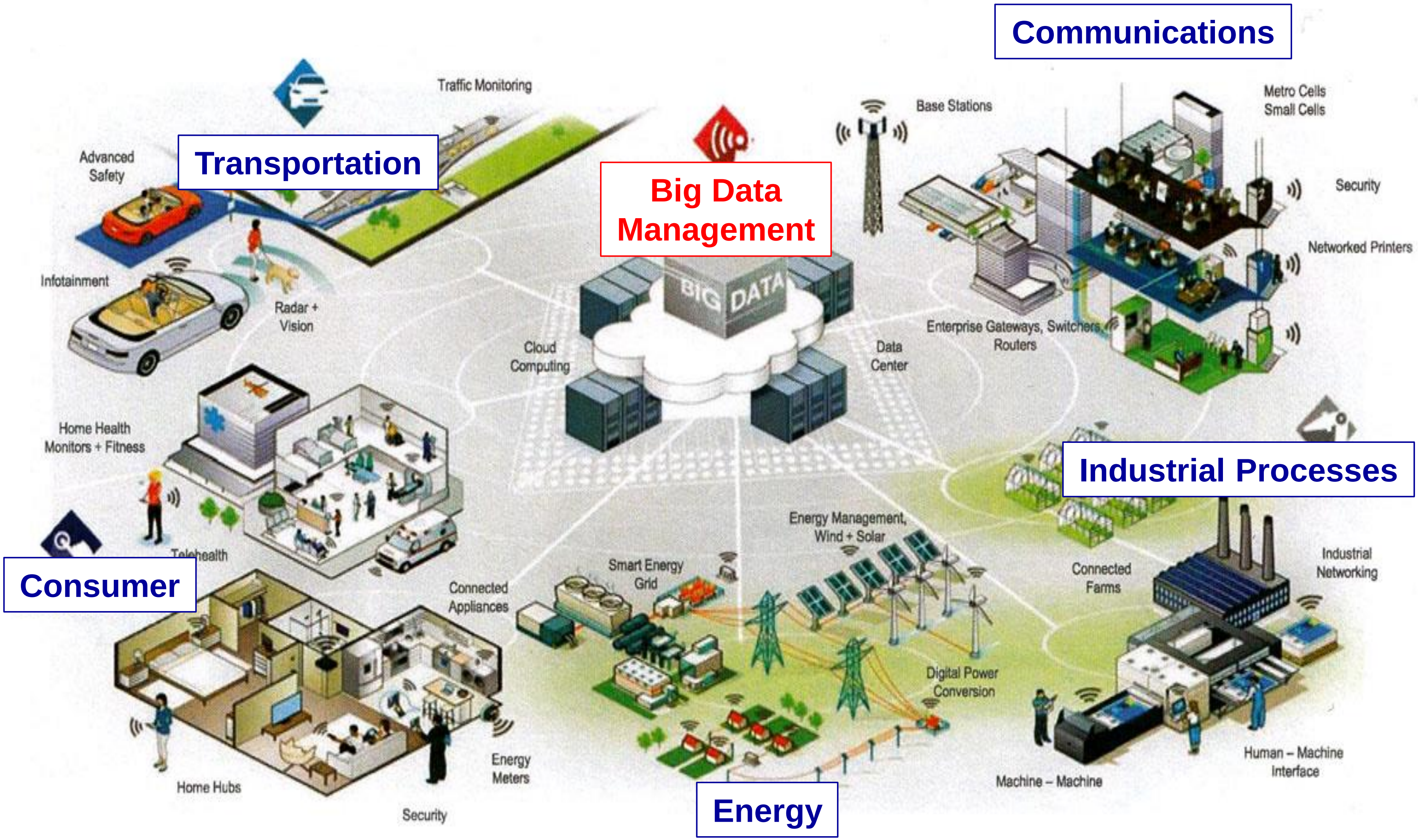
Big Data – “The Internet of Things”



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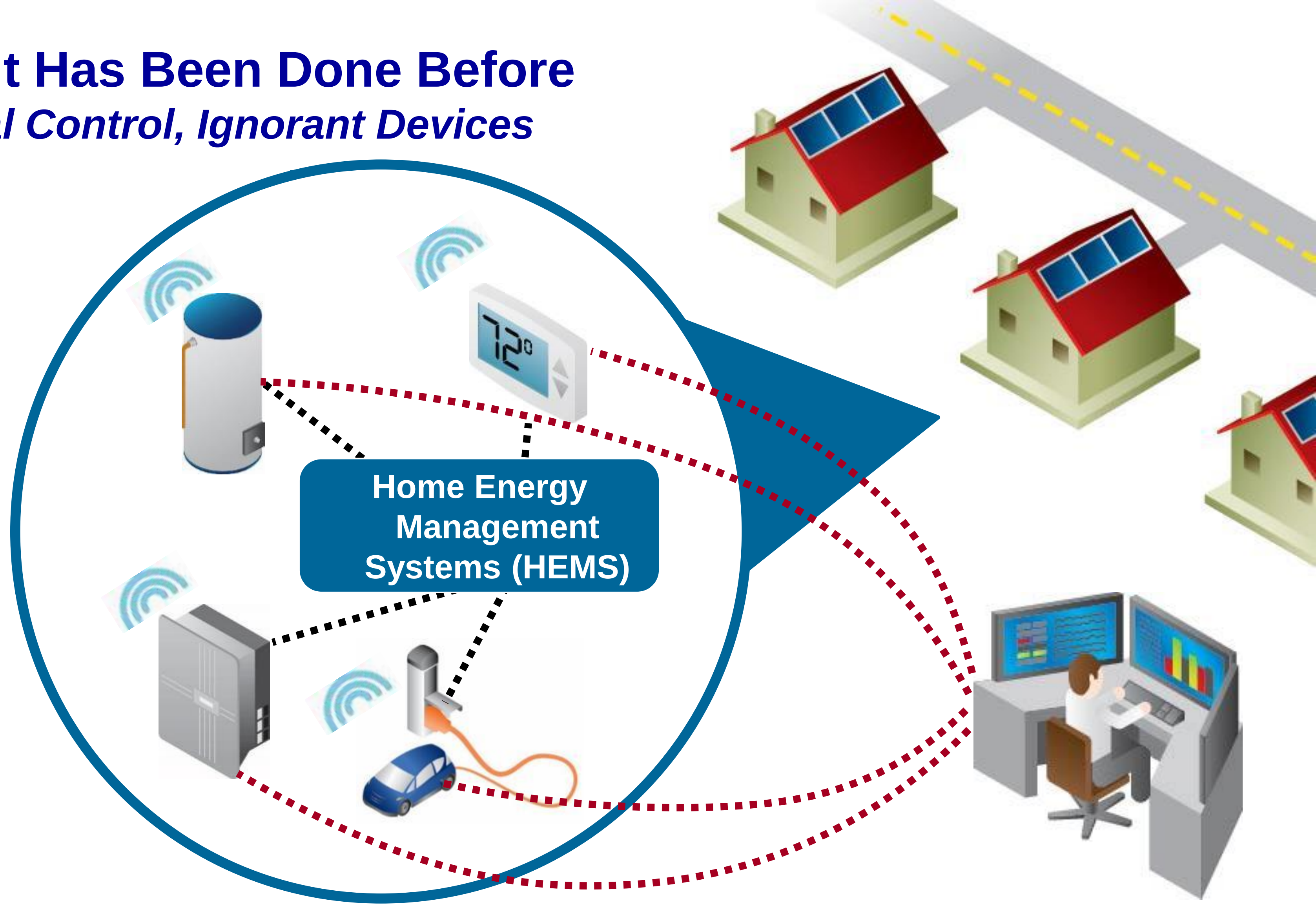
What is "Swarm Intelligence"?

- Used by ants and other creatures
- Enables control to be fully distributed among individuals (no centralized point of control or dependency)
- Each individual operates independently by following simple rules in response to local stimuli
- Members work together to accomplish group goals
- Widely used methodology
  - Telecommunications / network routing, simulating crowds, robot and drone swarms

Swarm intelligence is the collective behavior of decentralized, self-organized systems.

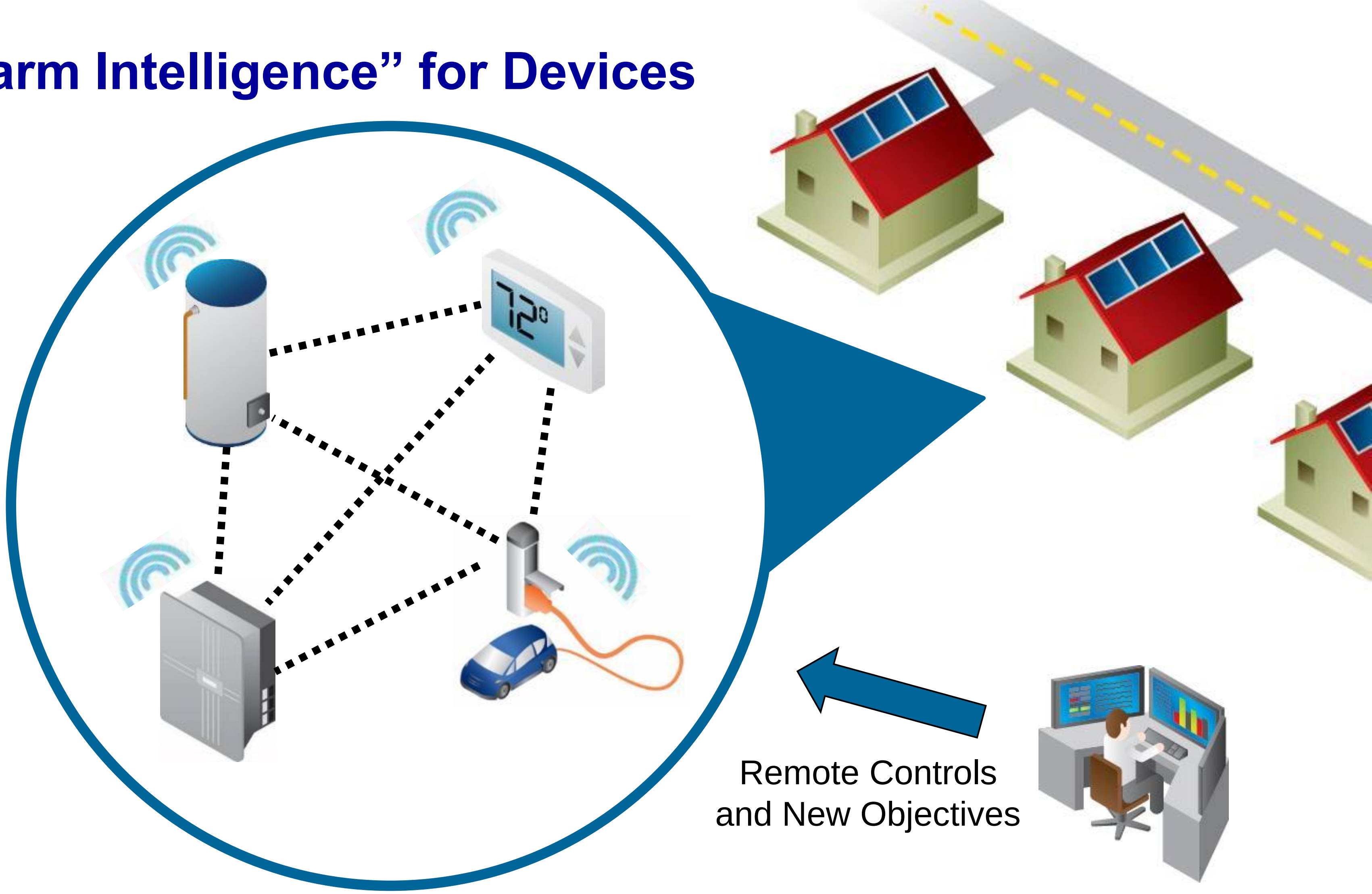
How it Has Been Done Before

Central Control, Ignorant Devices



Currently HEMS, utilities or aggregators must centrally manage distributed energy resources (devices) to coordinate their behaviors.

"Swarm Intelligence" for Devices

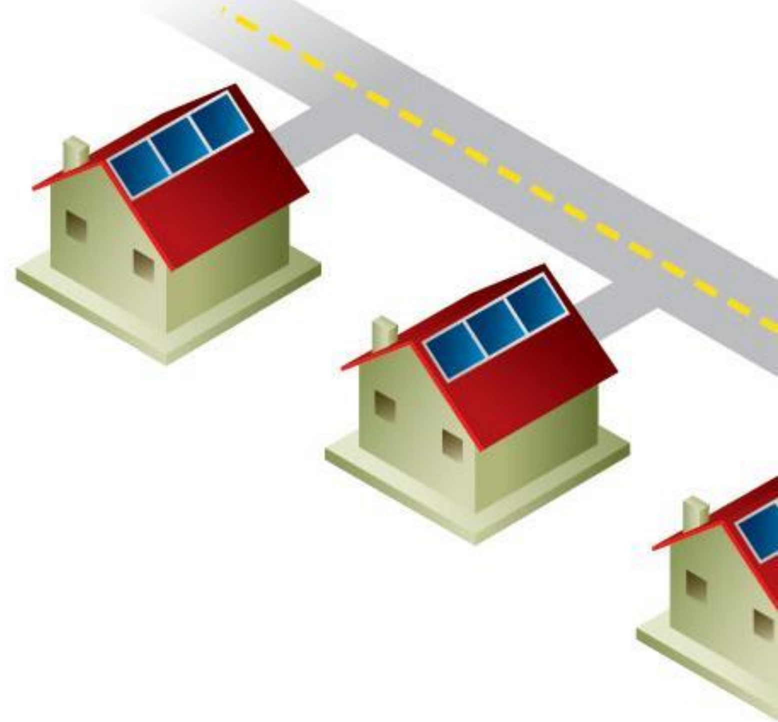


Devices with swarm intelligence will share information about themselves with other devices and work to achieve common goals.

"Swarm Intelligence" for Devices

State: Battery Charged
Mode: Off, Non-interruptible

State: Tank Temp Near
Mode: On, Interruptible



State: Approaching Setpoint
Mode: On-Interruptible

State: Generating
Mode: On, Curtailable

State: Tank Temp is Very Low
Mode: On, Non-interruptible

Social Behavior – Impact on Carbon Reduction

The Washington Post

Energy and Environment

The next energy revolution won't be in wind or solar. It will be in our brains.

By Chris Mooney January 22, 2015

Energy Office, Caley is tapping into one of the hottest trends in academic energy research: looking to use psychology and the behavioral sciences to find ways of saving energy by changing *people* — their habits, routines, practices and preconceptions.

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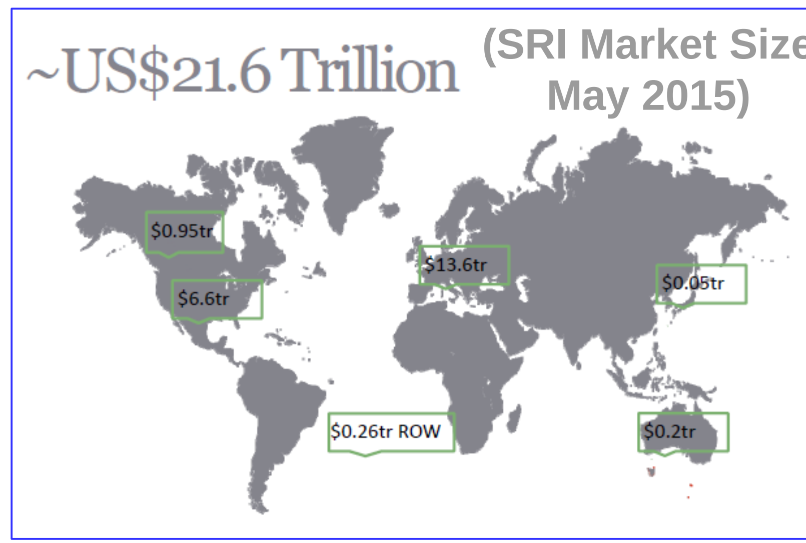
Access to Capital – Investors Influenced by Sustainabilty

- Corporate Financial Filings
- Lending Institutions adopting "Equator Principles"
- Millennials will drive change
- 433 environmental, social, governance resolutions in 2015
- (Independent) SASB identifying issues that are material at an industry-level ("Material issue" has potential to impact firm's financials)



SASB Sustainability Accounting Standards Board
Bloomberg
Dow Jones Sustainability Indexes
NASDAQ Sustainability Index

Source:http://www.ncpers.org/files/Conference%20Docs/Annual%20Conference/2015%20PPT's/Chris%20Mcknett%20The%20Art%20and%20Science%20of%20ESG%20Investing_5.4.2015_Final(1)(CM).pdf

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A Look Ahead
More Change in the Next 10 Years than in the Last 50 Years

Together…Shaping the Future of Electricity