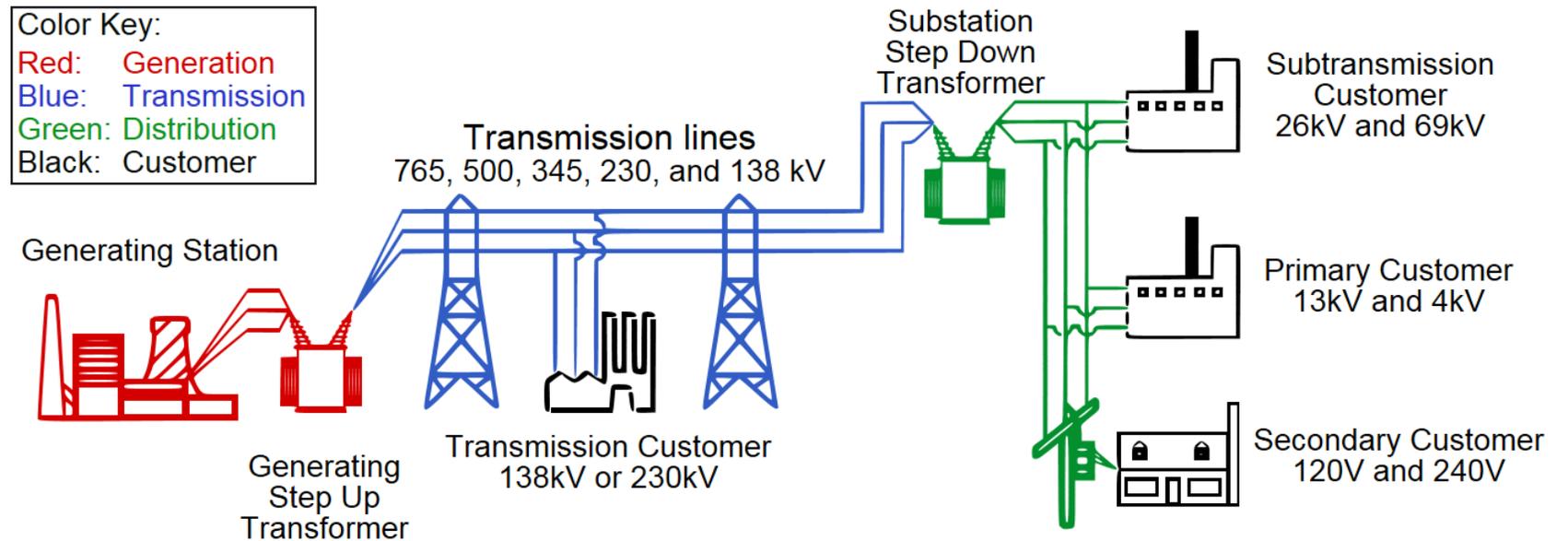


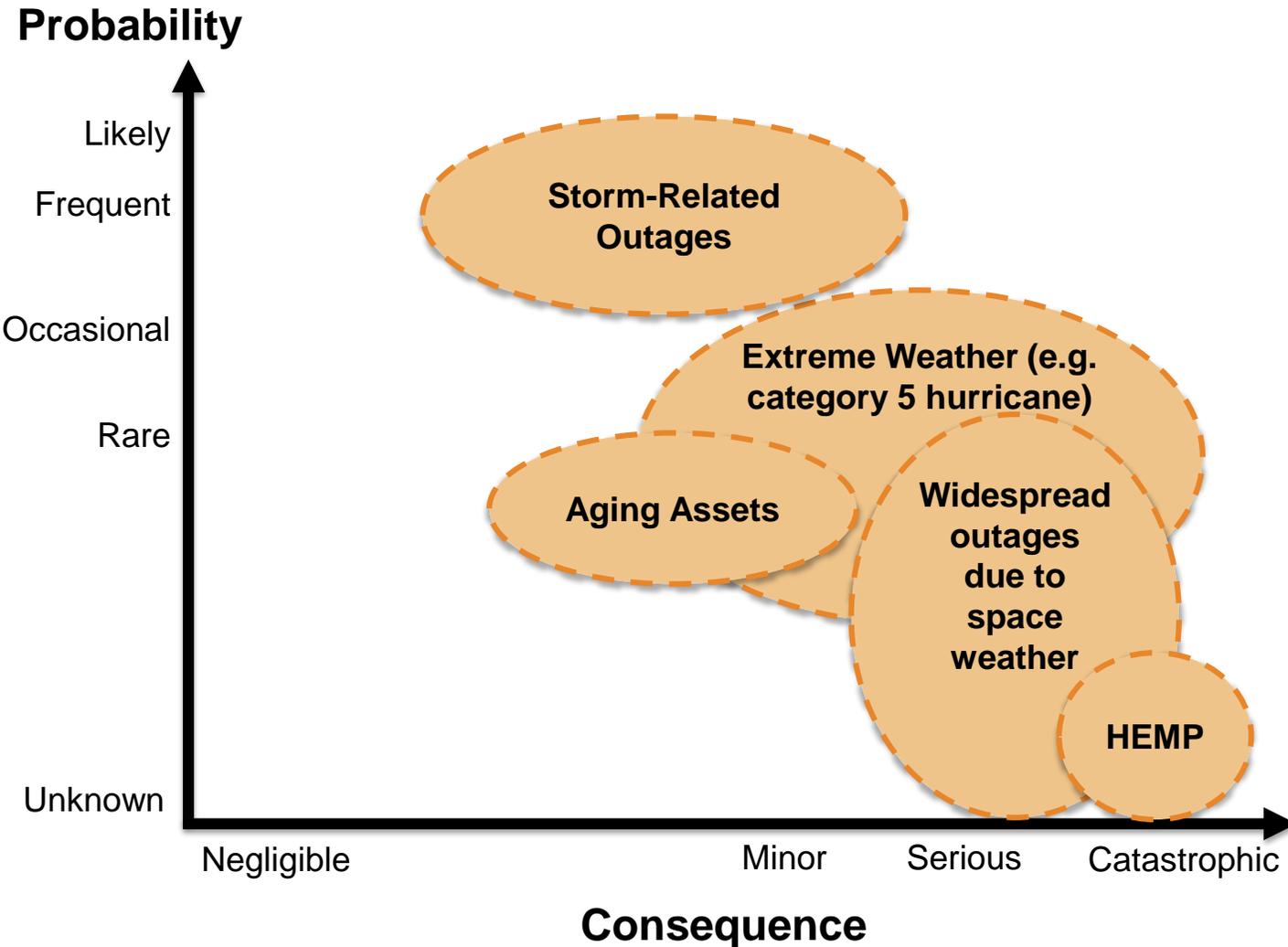
# SWITCHES on Steroids (SOS): Making Gains in Grid Hardware



Dr. Isik C. Kizilyalli

March 15, 2018

# What are the major risks to the electricity sector?



**Average Annual Cost of Grid Disruptions:**

**\$18 to \$33 billion**

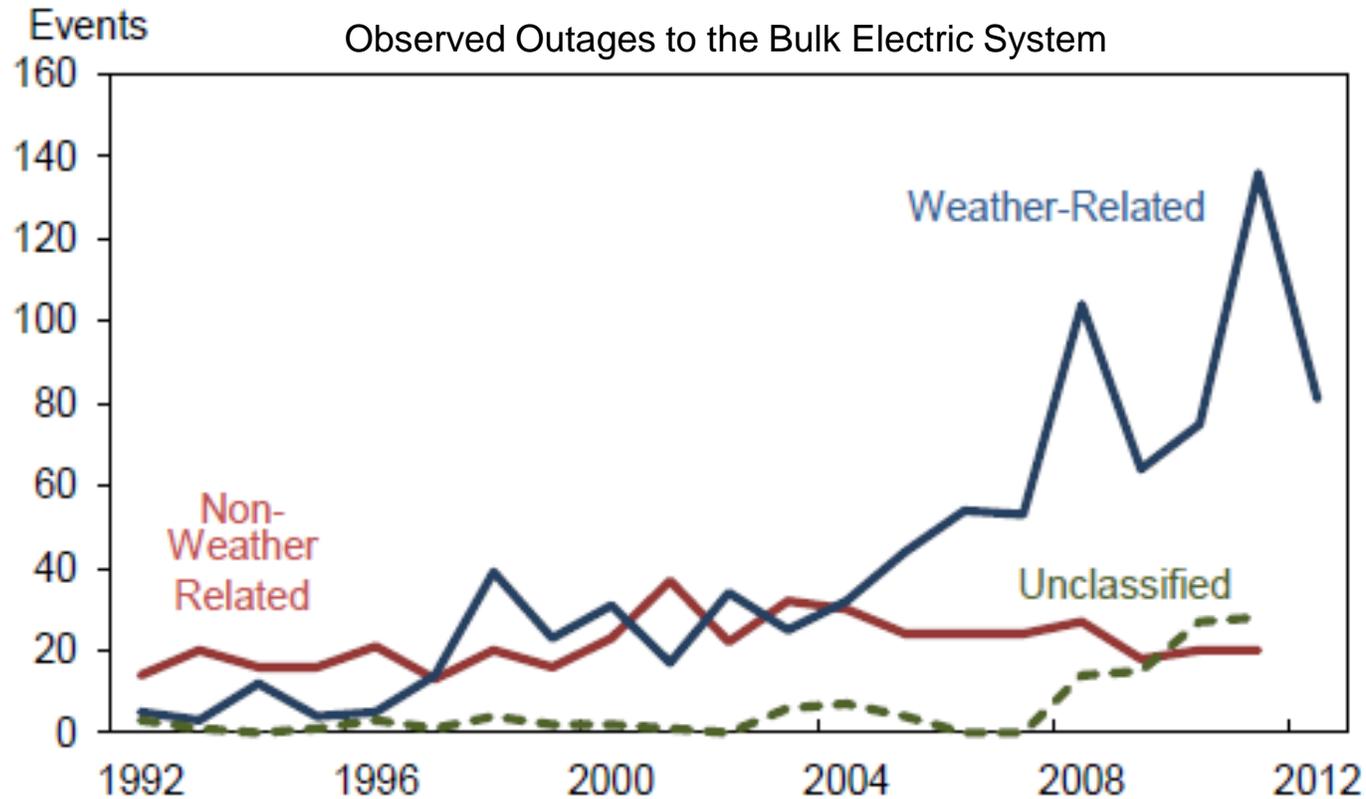
**Solution:**

**Harden Grid Components  
&  
Hasten Recovery**



# Weather-related outages have increased

5-20 outages per year in the mid-1990s... **50-100 per year in the last 5 years**



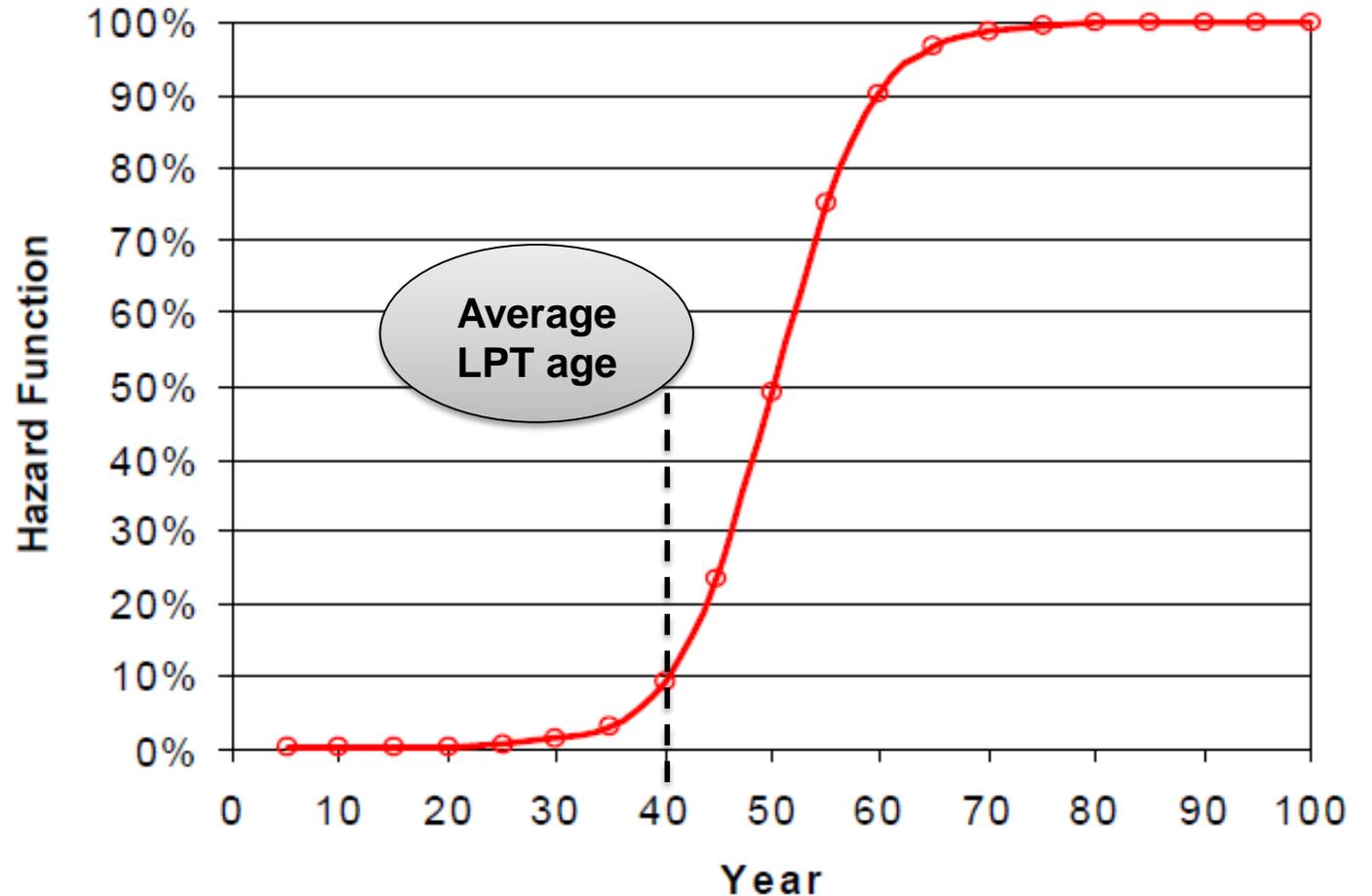
Source: Energy Information Administration



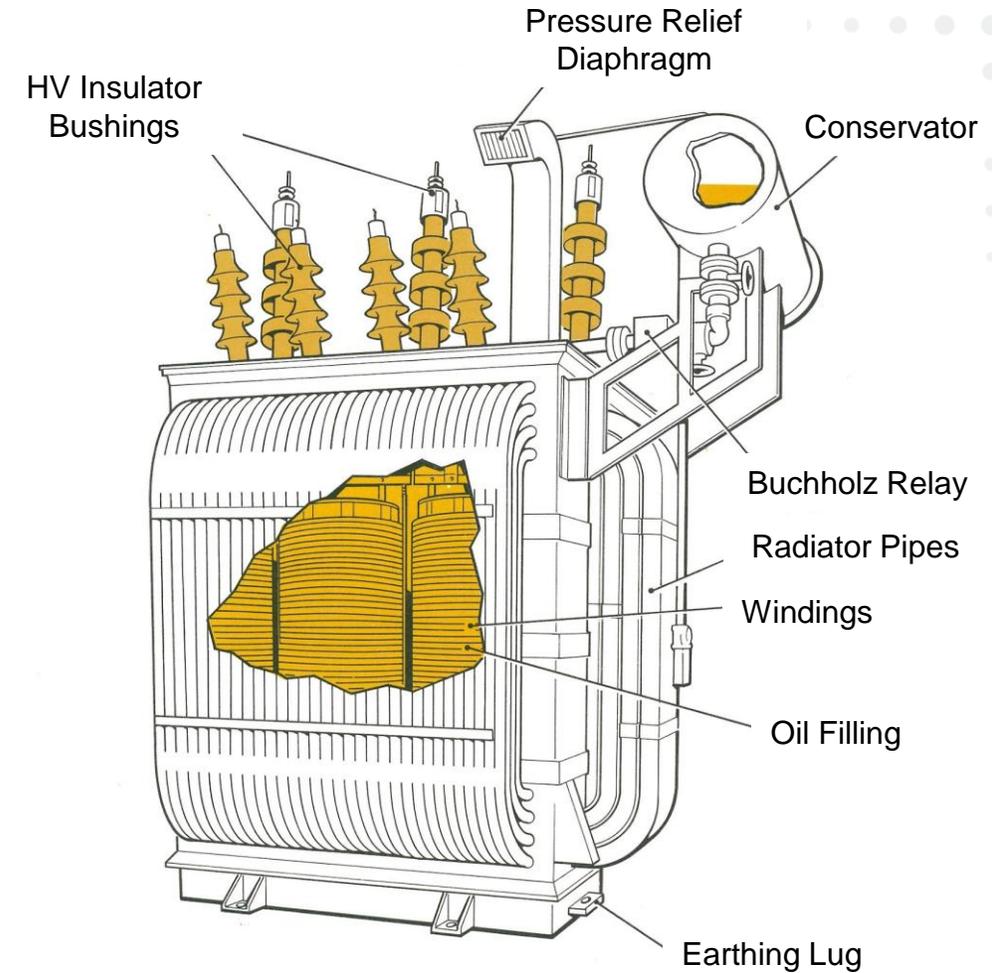
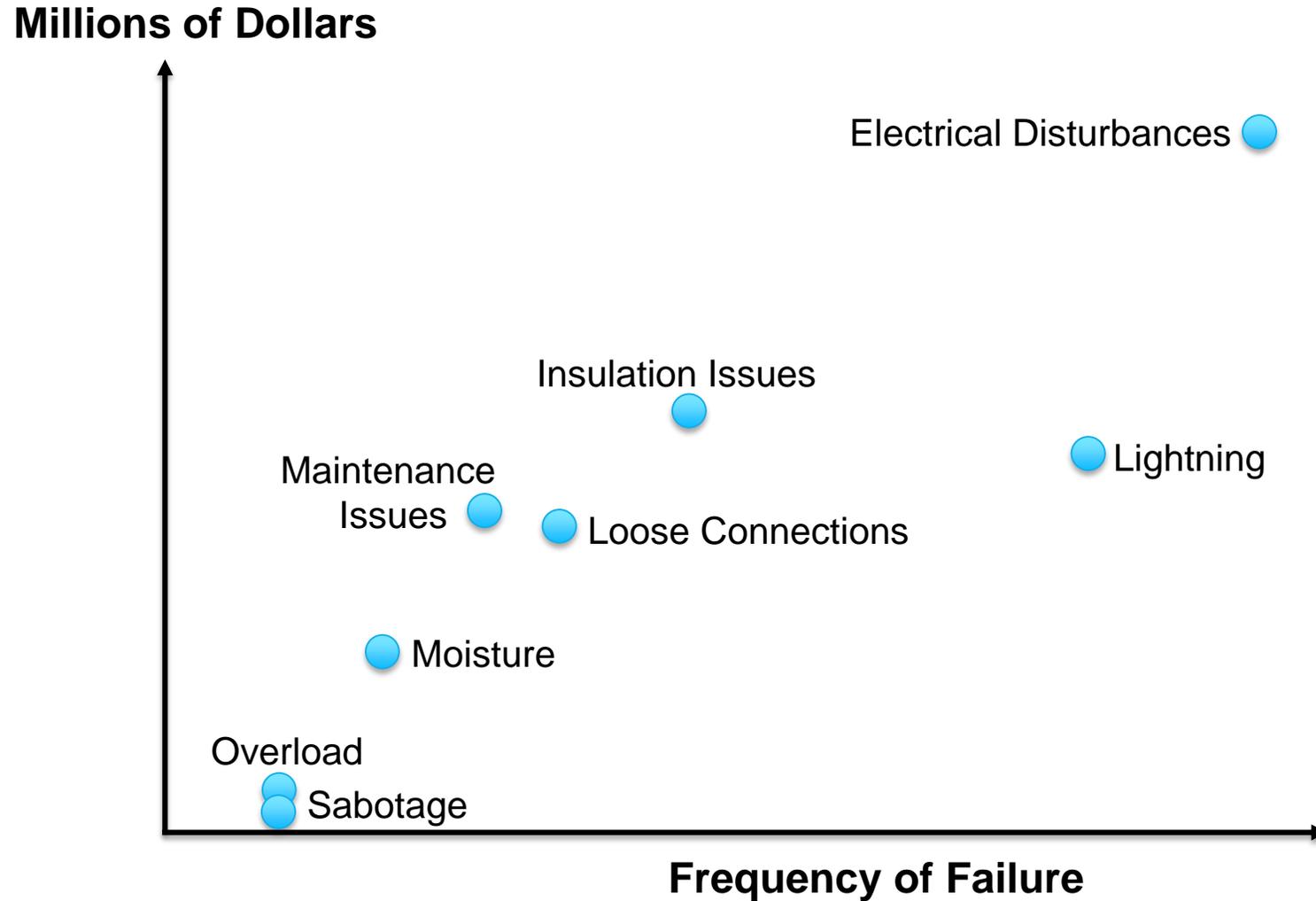
# Key infrastructure is nearing the end of its designed lifetime



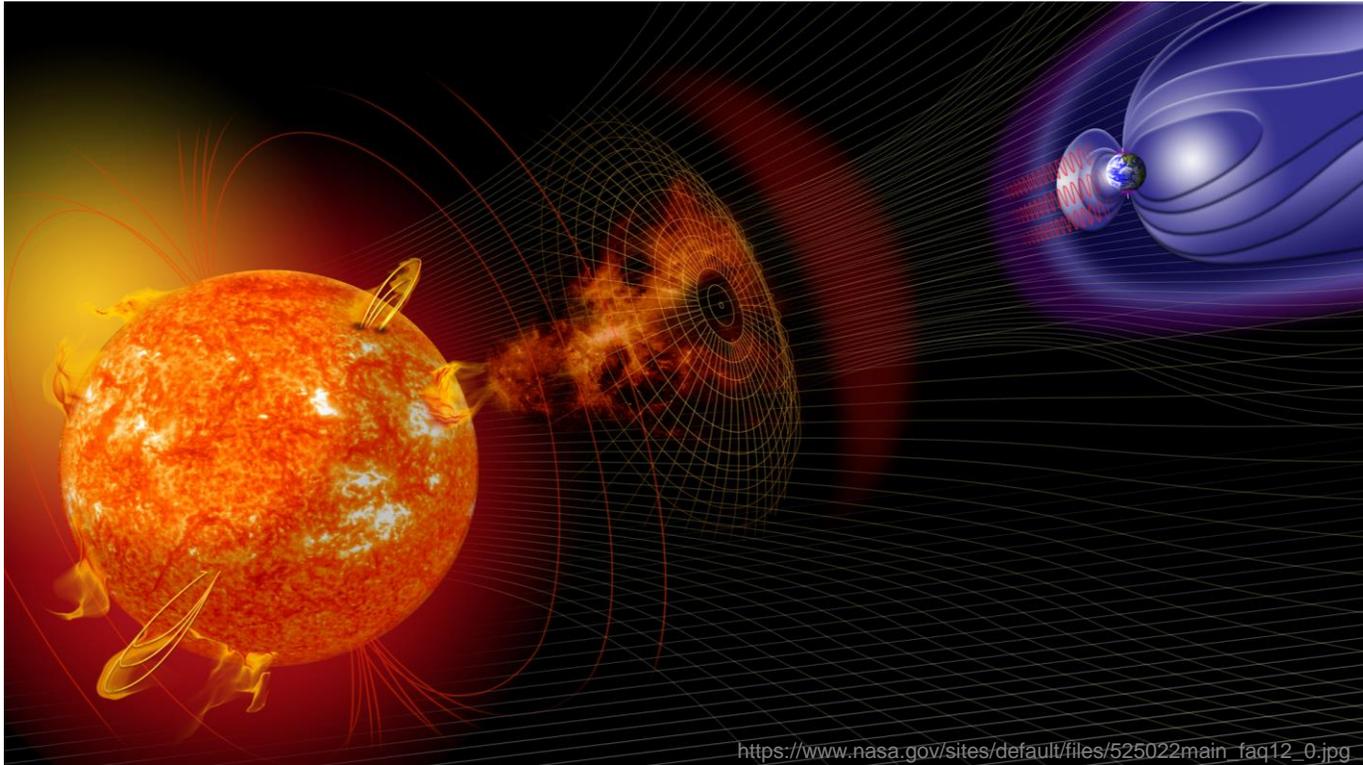
Large Power Transformers (LPTs) carry > 90% of the Nation's power  
**70% are 25+ years old**



# Why do transformers fail?

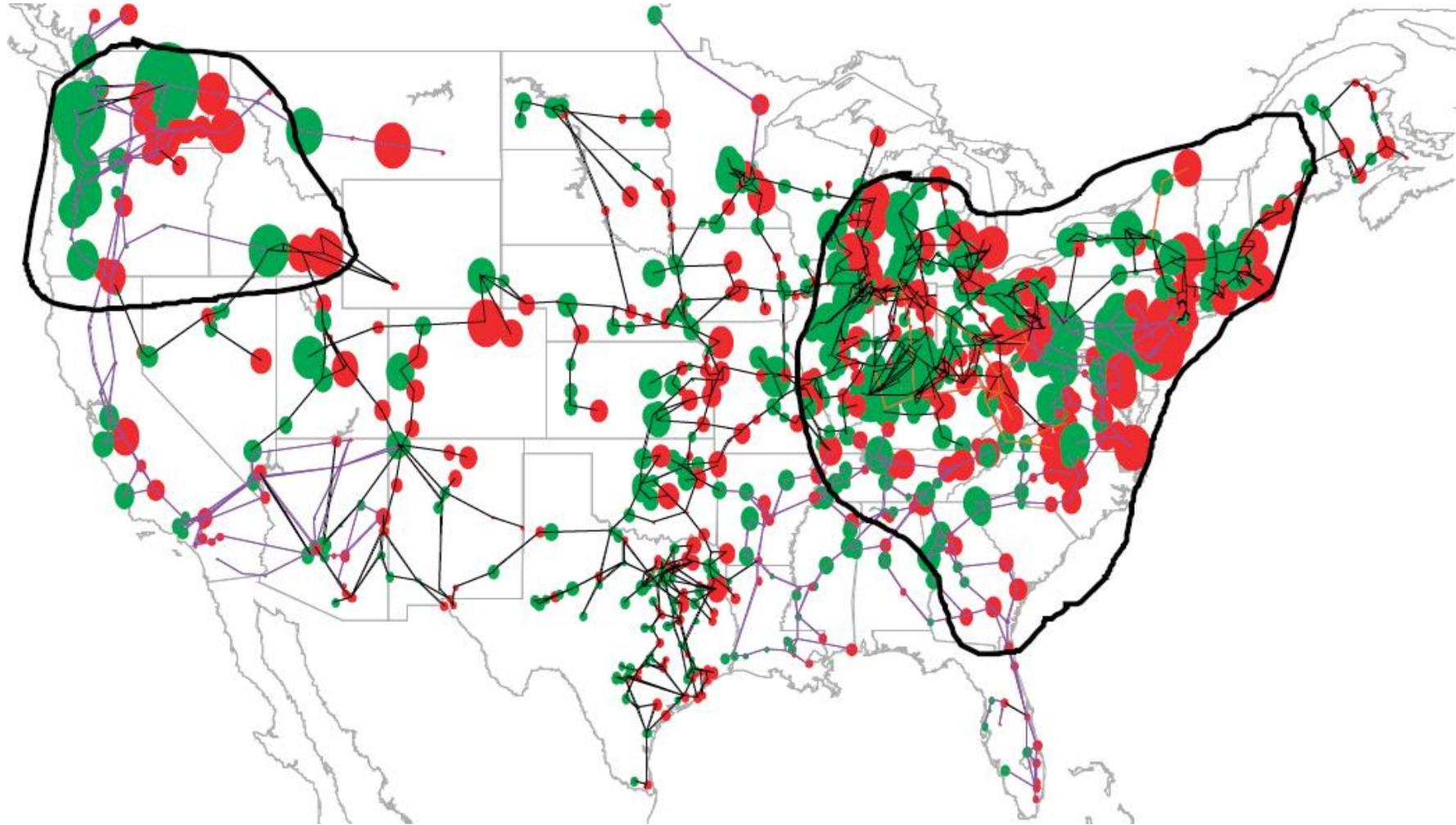


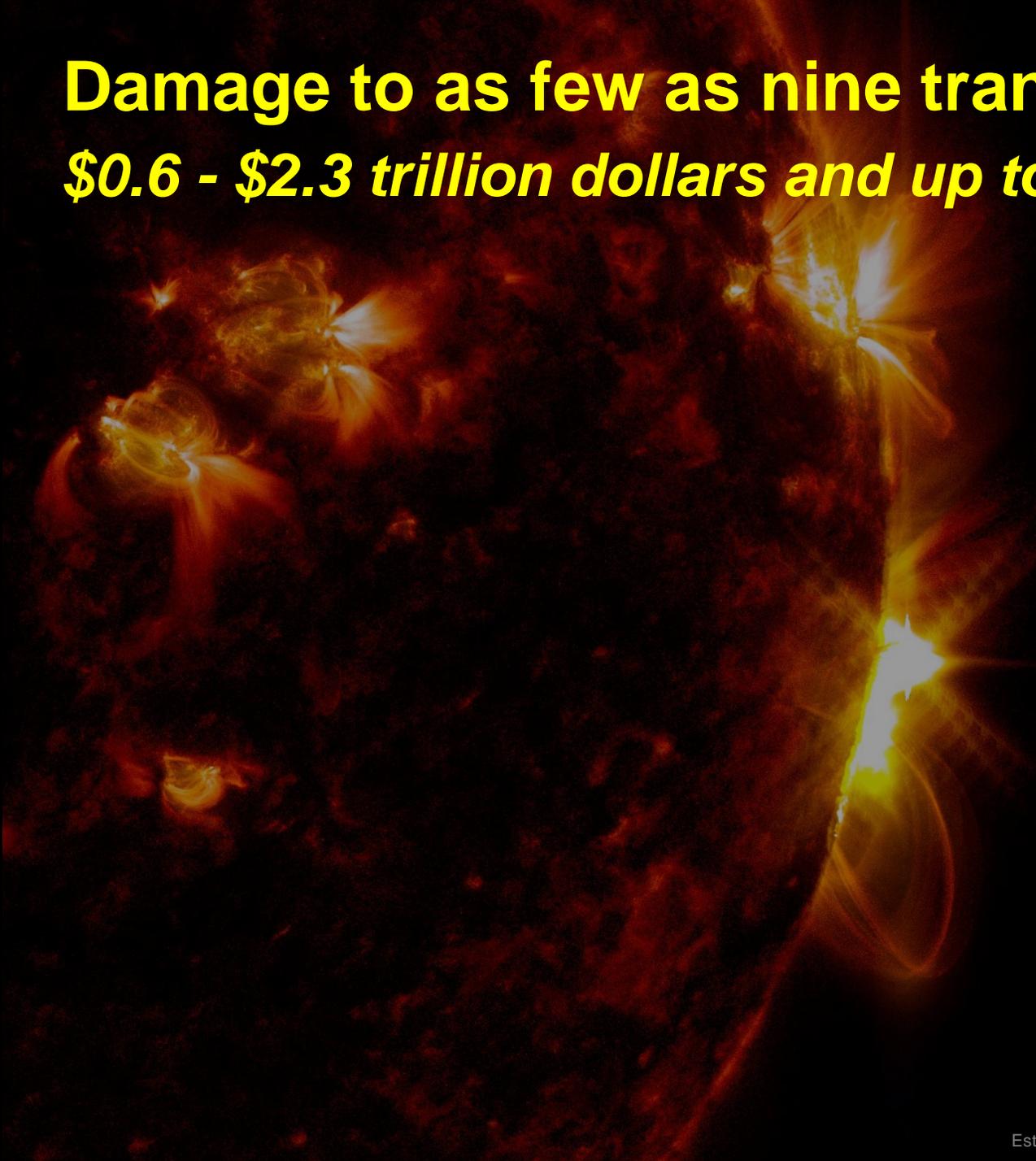
# Space Weather and Northern Lights: Carrington Event 1859



Expected occurrence of coronal mass ejection similar to Carrington is 150 years

# Geomagnetically Induced Current (GIC) flow into transformer and from transformer





**Damage to as few as nine transformers puts millions at risk**  
***\$0.6 - \$2.3 trillion dollars and up to 10 years for full recovery***

**Potential Impacts of a Solar Flare**

**Instant**

**Telecom and Internet  
Air Traffic Control**

**Days**

**Food Supplies  
Financial Infrastructure  
Backup Power**

**Weeks**

**Clean Water  
Disease Outbreaks**

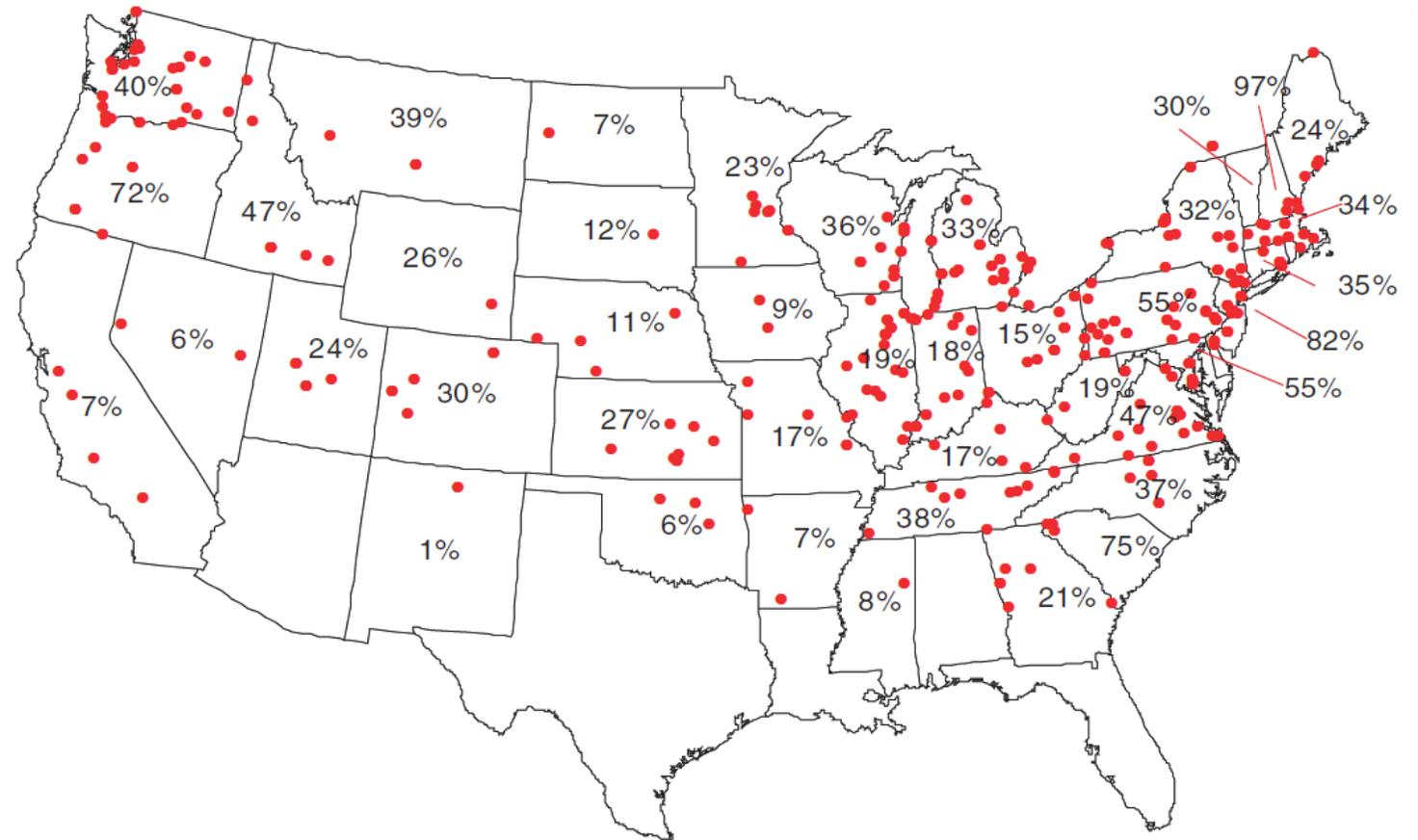
# Severe space weather can shut down numerous grids simultaneously

## % of Large Power Transformer (LPT) capacity at risk

**Worst-case scenario:**  
1859 and 1921  
Magnetic Storms

**>300 LPTs at risk**  
(of ~2,500 total LPTs)

**>130 million people affected**



# Replacement challenges compound the risk of a mass outage

2-6 months

Propose,  
Negotiate,  
Contract

4-8 months

Design &  
Purchase  
Materials

2-5 months

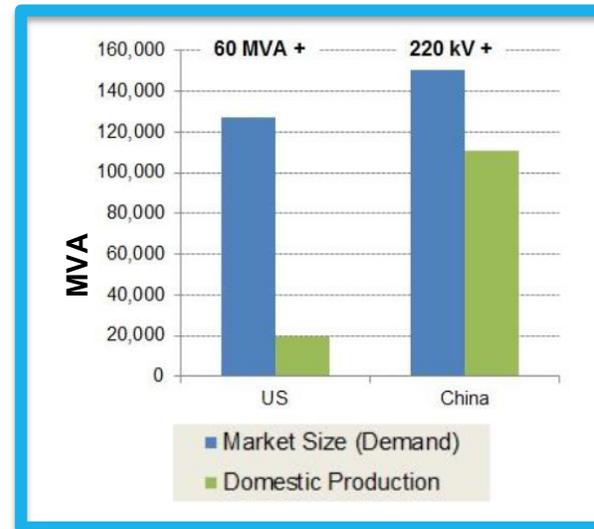
Production &  
Testing

Weeks to Months

Transport &  
Set Up

- **1.3 transformers** made for each design
- **500 LPT** produced globally

Minor U.S. Production

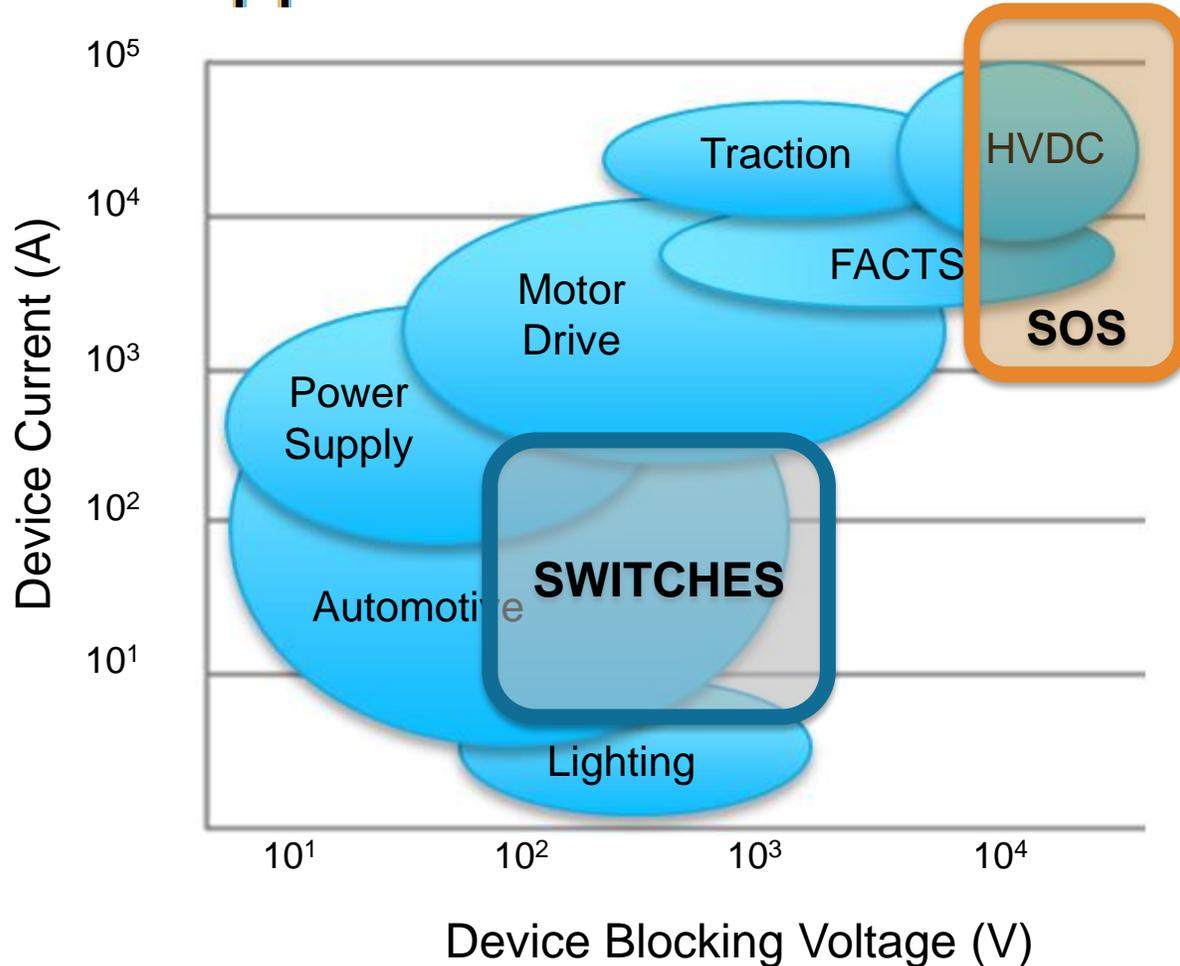


Transportation Challenges



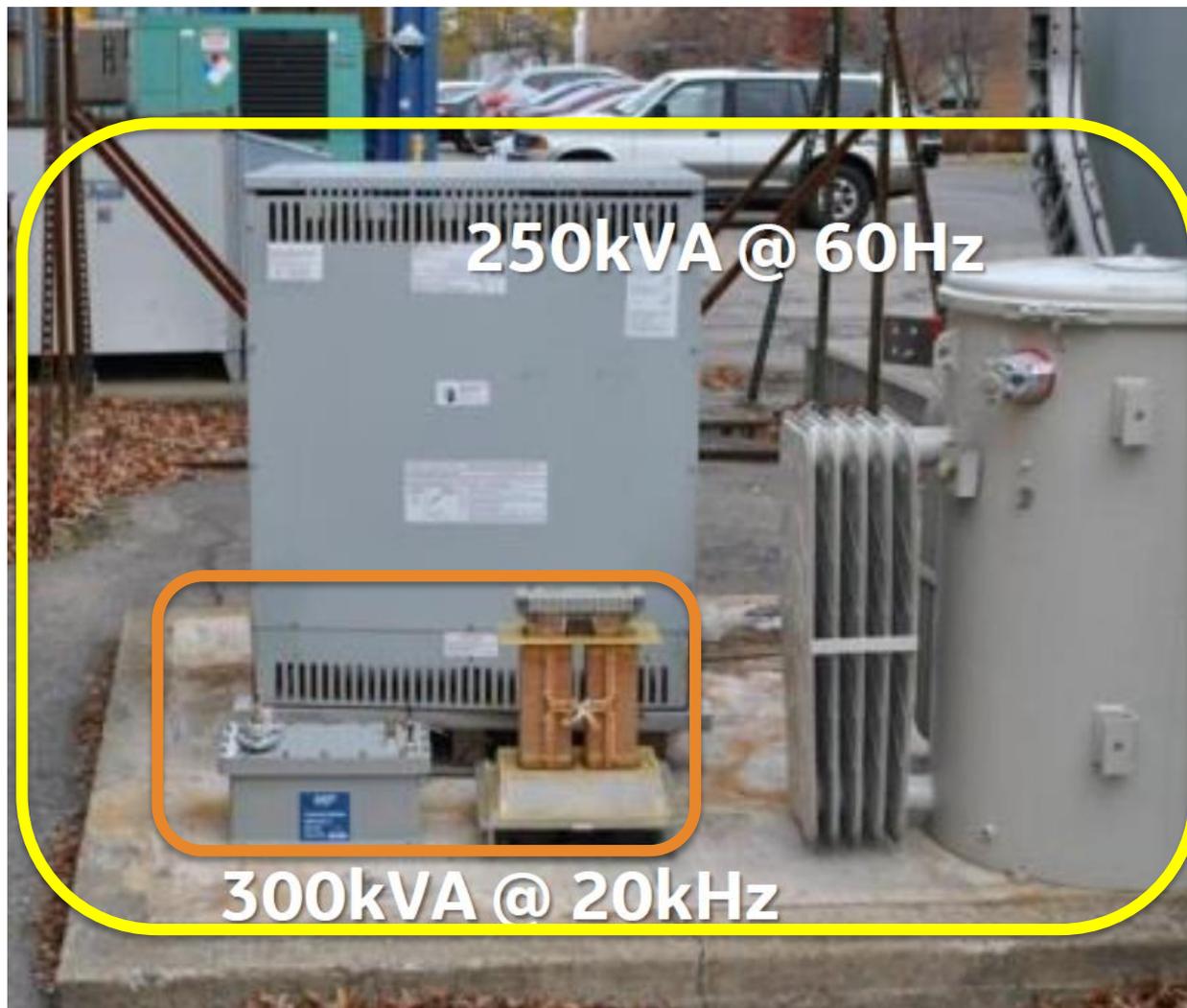
# SWITCHES on Steroids (SOS): Power electronics for grid security

## Application Areas and Limits



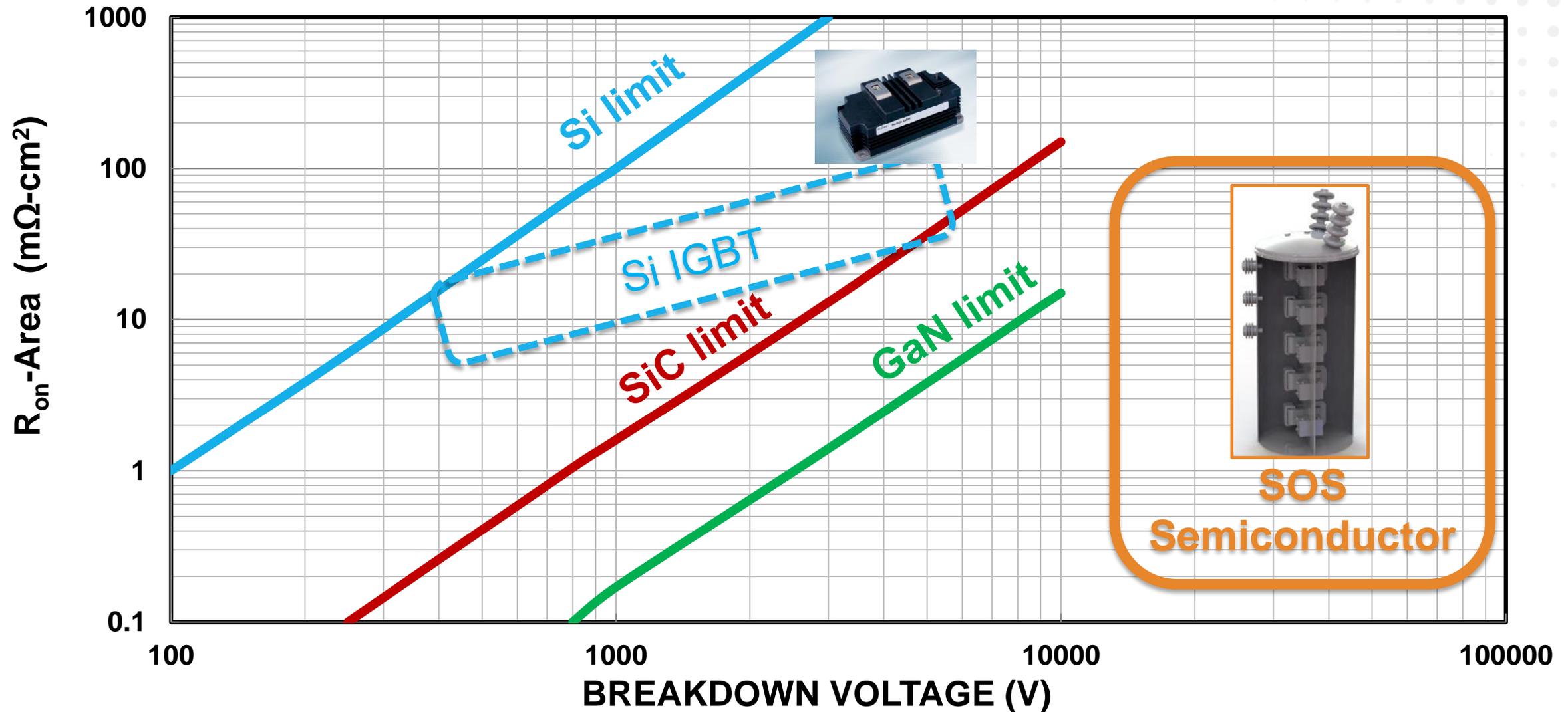
- Semiconductor Electronic Transformers
- Gas Tube Devices
- Large Power Transformers *Reimagined*
- Cables, Conductors, and Construction

# Size and weight reduction gains are promising at lower voltages

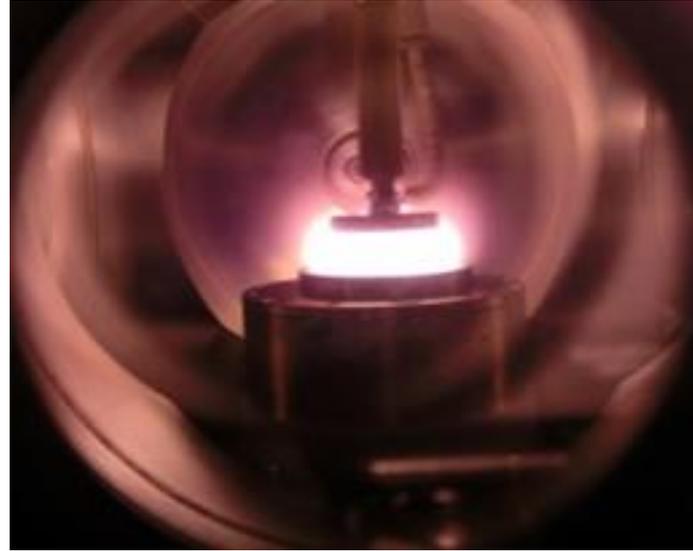
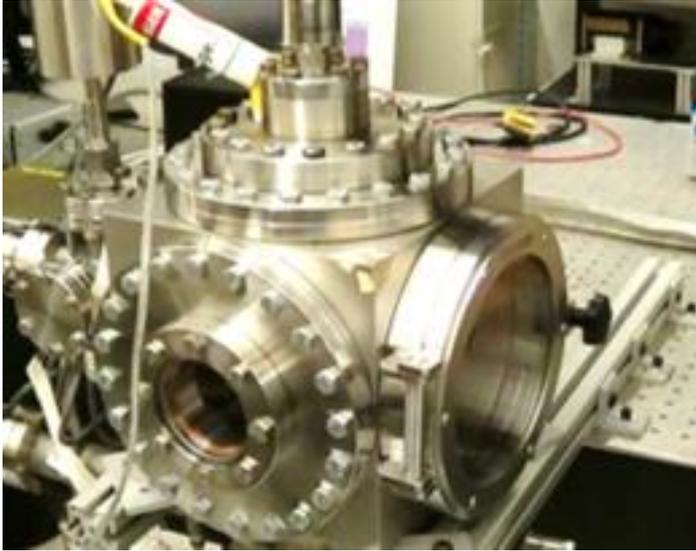


Imagine a 10-100-fold reduction in the size and weight of large (250MVA) power transformers!

# High-Voltage (20+ kV) Semiconductor Device Challenge



# High-Voltage, High-Power Gas Tube Technology for HVDC



>300 kV

Longer lifetime - self-healing cathode and plasma

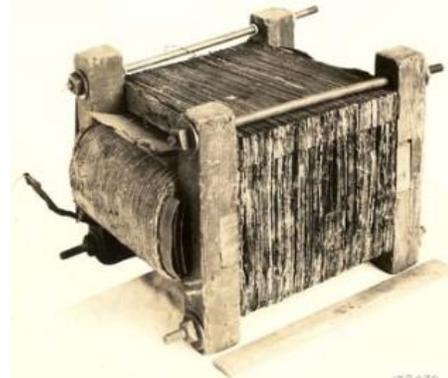
Low-loss mode of operation

**Expected to reduce overall HVDC terminal cost by 40%**

# Large Power Transformers Reimagined for the Future Grid



1885

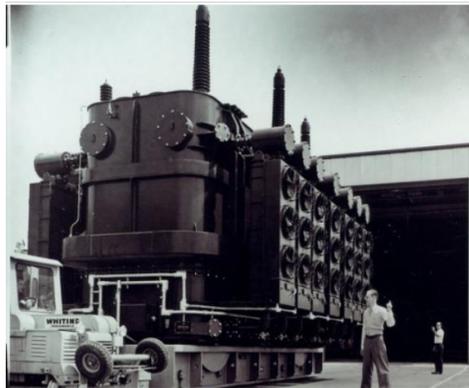


1886



1917

1953



2014



2050



# Goal: ZERO power interruptions to the grid by 2050



## ***HARDEN COMPONENTS***

### **Replace and Modernize**

- Switches
- Surge Arrestors
- Power Flow Controllers
- Cables and transmission lines
- Transformers

### **Emphasis on:**

- Higher heat tolerance & radiation hard
- Improved size, weight, efficiency, & cost



## ***HASTEN RECOVERY***

- Rapid surge protection (1ns response to  $\epsilon_1 \approx 10^5 \text{V/m}$ )
- Improved functionality (MVDC and HVDC)
- Fast turnaround manufacturing
- Modular designs
- Simple installation
- Integration of intermittent resources

**Thank you!**

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