



The future grid

Engineering Dreams



NRECA

A Touchstone Energy® Cooperative 

Do we need a new grid?

NO

- The grid is an amazing achievement and it works exceptionally well
- It is recognized as the greatest engineering achievement of the 20th century by the National Academy of Engineering



We could sustain reliable and cost effective delivery of electricity through basic maintenance and extension using conventional technology

But ... that's not the way engineers do things

- From the first – engineers and utilities have asked – *how can we do it better?*
- Every component and every procedure has been relentlessly refined, relentlessly polished.

Engineers Dream

Past, Present, and Future

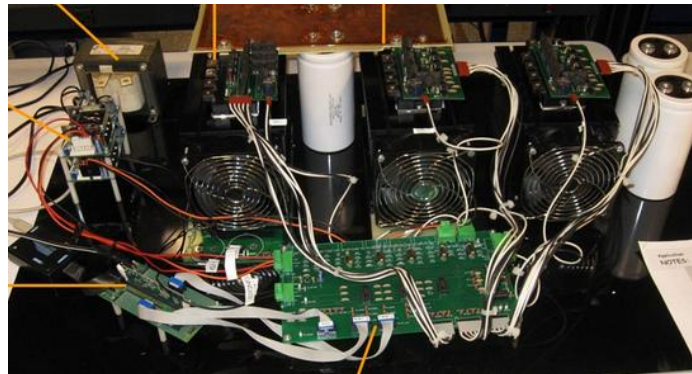
1883 first deployed transformer



Current distribution transformer



**The future? solid state transformer,
Dynamic voltage control at the edge.**



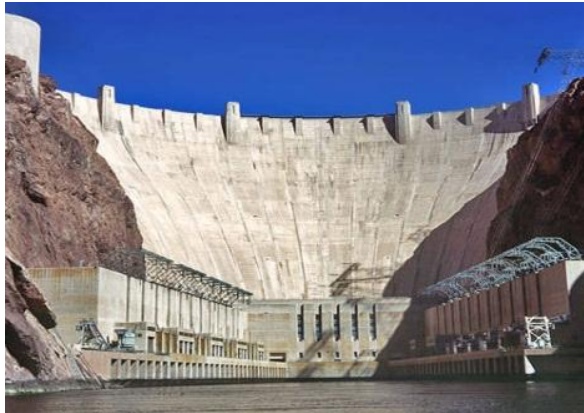
The grid “evolves” in small steps

- “The mother of every chicken is a chicken, the daughter of every chicken is chicken” Richard Dawkins
- --the grid looks the same, day to day, but over time it is essentially reinvented
- This is true because:
 - The grid is immensely complex – vastly beyond “simple” things like the Apollo program.
 - Different portions of the grid are independently configured and controlled – there is no “Deus ex machina”.

Will the future grid be smart?

YES, the grid will be smart

- *Smart is the alternative to big.*
- When the grid was first built, it was all about expansion – more power, delivered ubiquitously



- When you reach a limit, you built MORE
- Why we still focus on more, but the first thought now is getting more from what we have.

Engineering Dreams

(with respect to Henry Petroski)

Every new tool or material allows and encourages an engineer to rethink every aspect of a problem – Solid state technology is the new tool that is allowing engineers to ‘dream’ the smart grid.



Wood

Stone

Concrete

Iron

Steel

Fiber

And Shockley said “let there be transistors”

The rate of the improvement in grid components was slowing in the 1980s. --

Electricity prices were low and stable

Reliability was very high

“Everything had been invented”

Then – solid state electronics entered the power industry

metering

communications

control

power electronics

And it was time to reconsider / reinvent everything



(731 million)



Living in the Interesting Time

1883→ 1990

Control Through Angular Momentum



Reliability through overbuilding

Transition

2025?→ ...

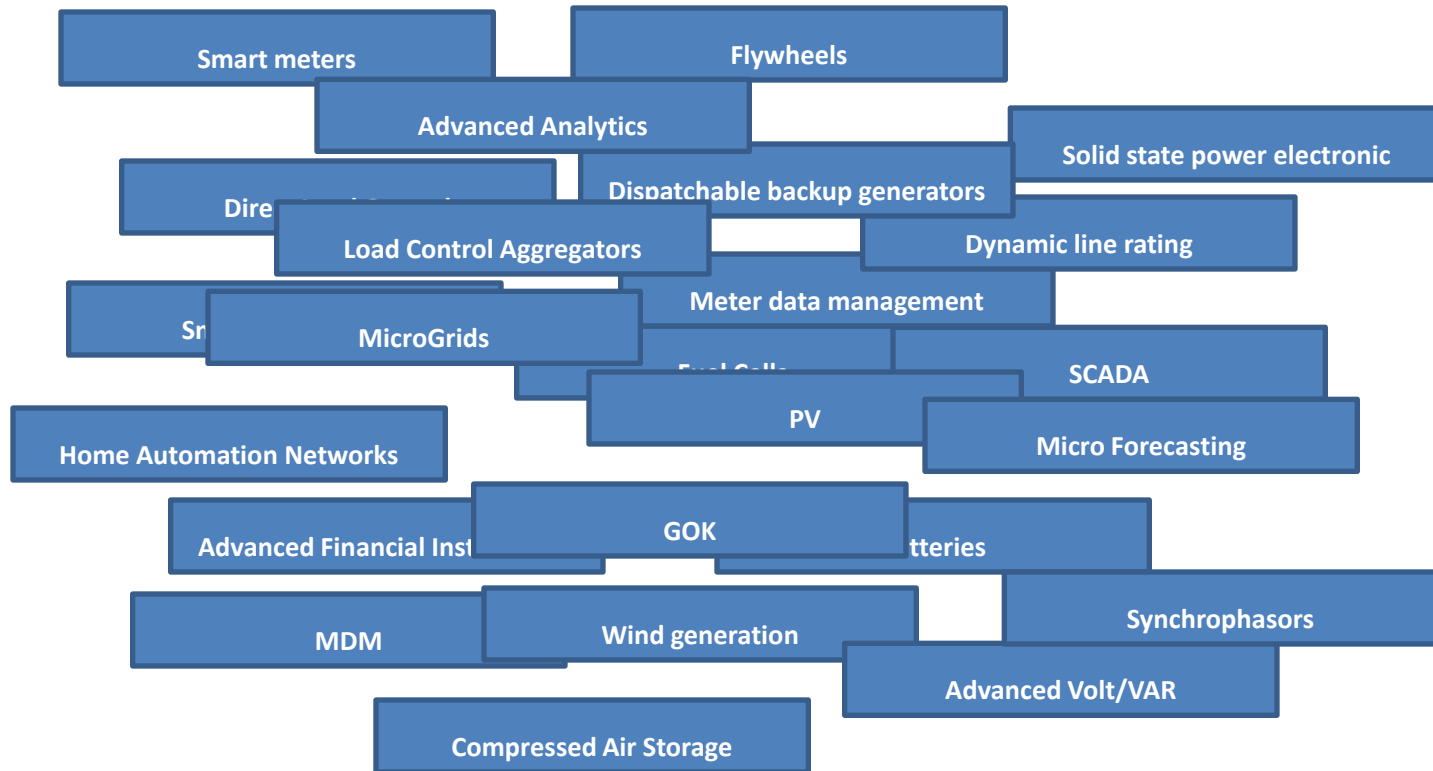
Analytically Driven Control



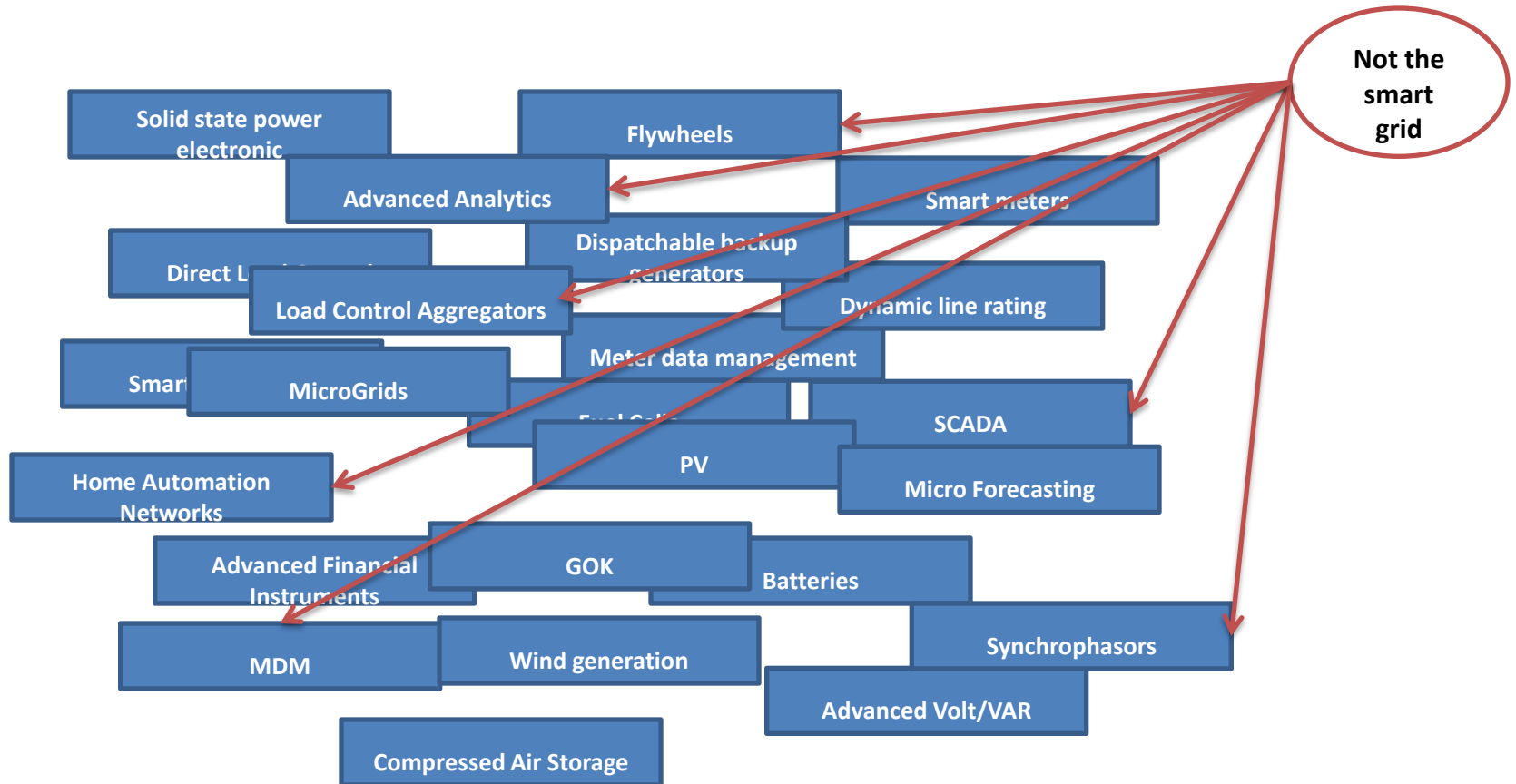
**Lack of overall model
Changing Technology
Complicated Transition**

**Knowledge of state
Precise control
High performance analytics**

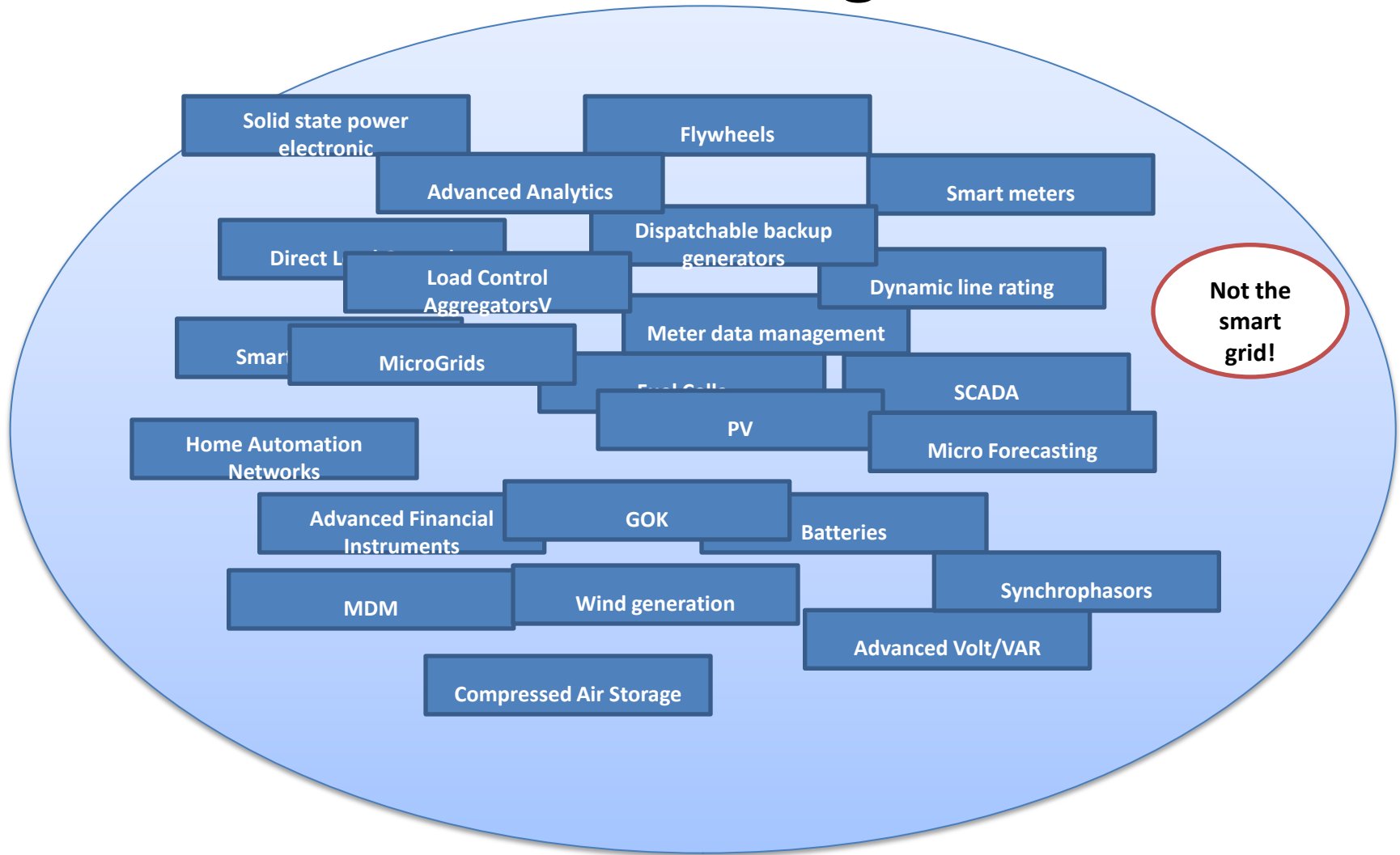
The smart grid encompasses many ideas and many technologies



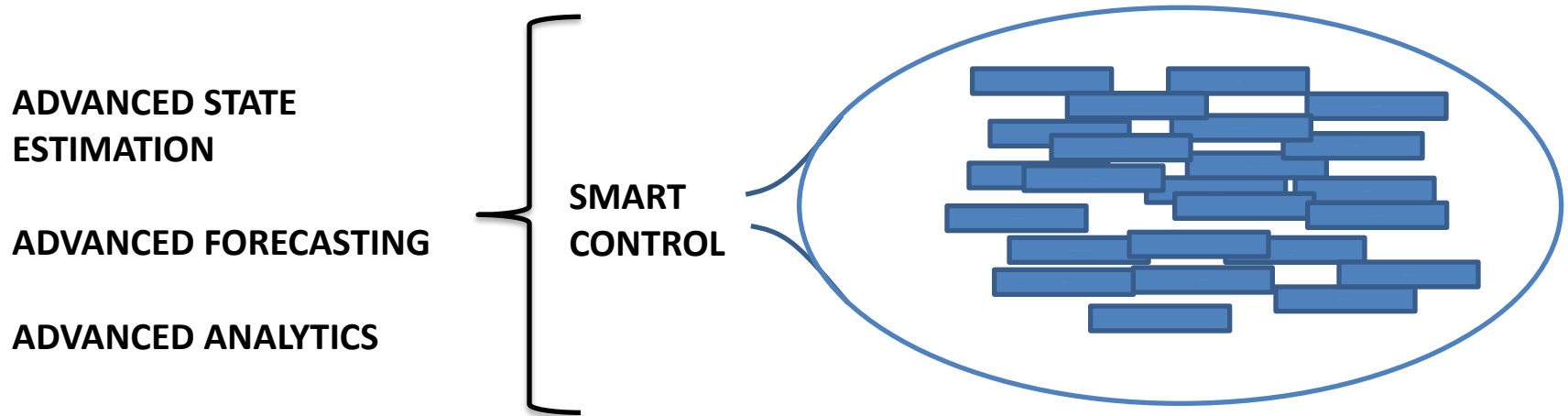
But the smart grid is not one technology



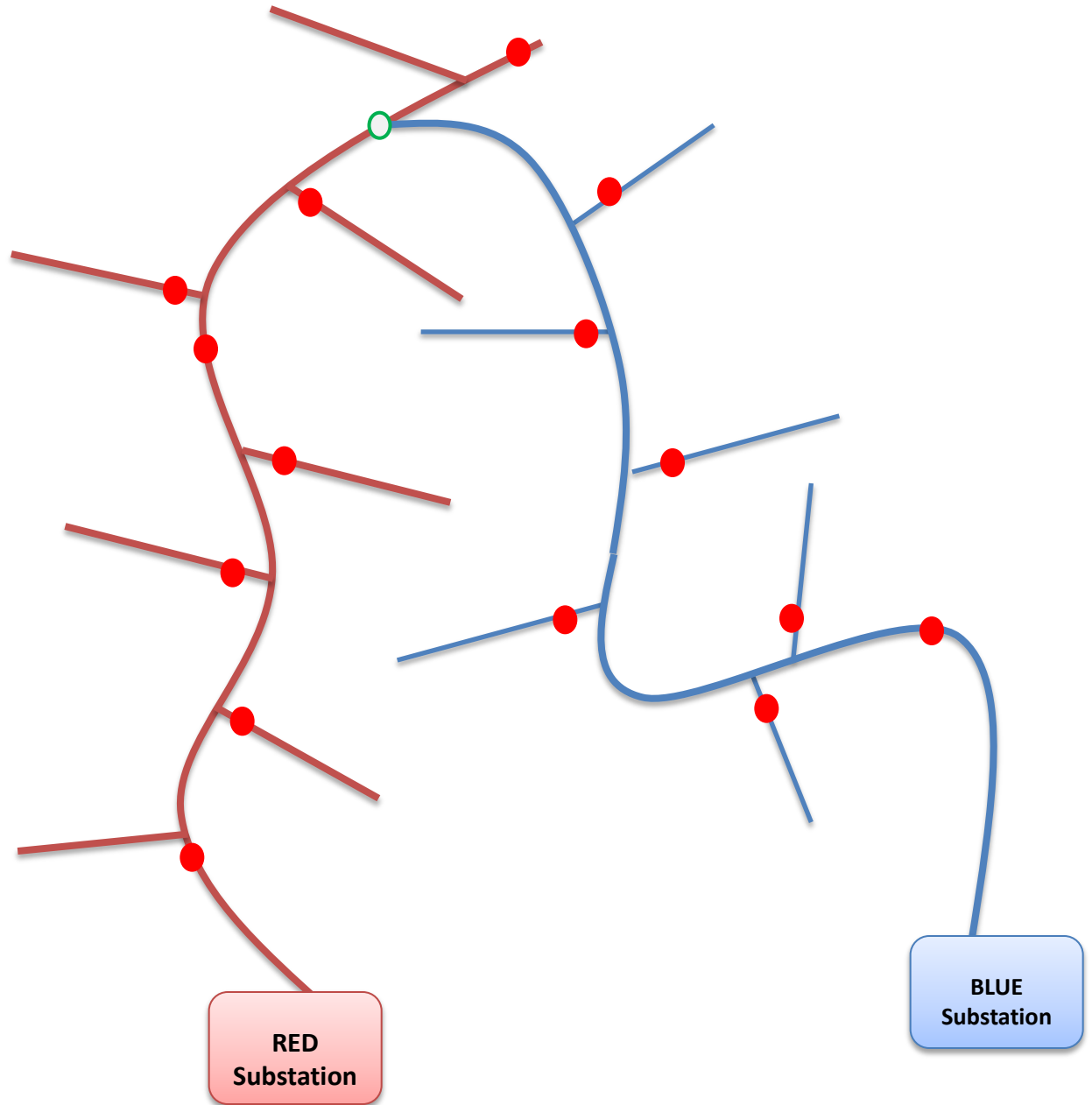
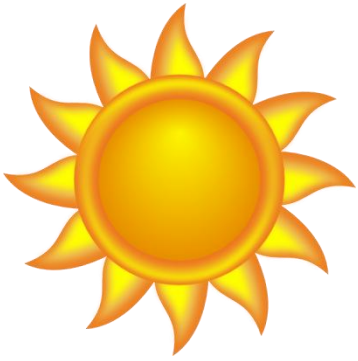
The smart grid is not a collection of technologies



The smart grid IS the “smart” application of diverse and improving technologies to improve grid design and operation

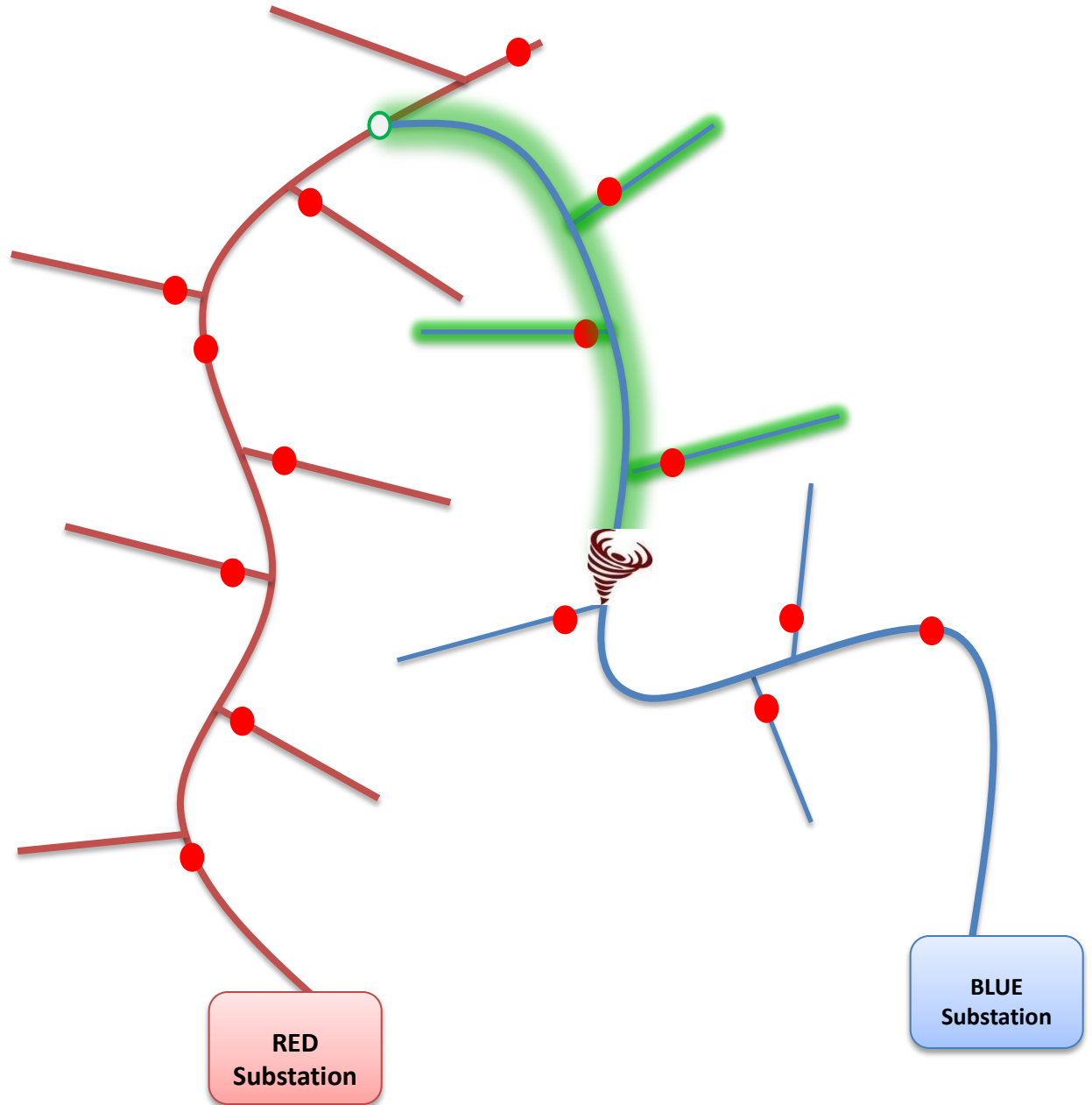


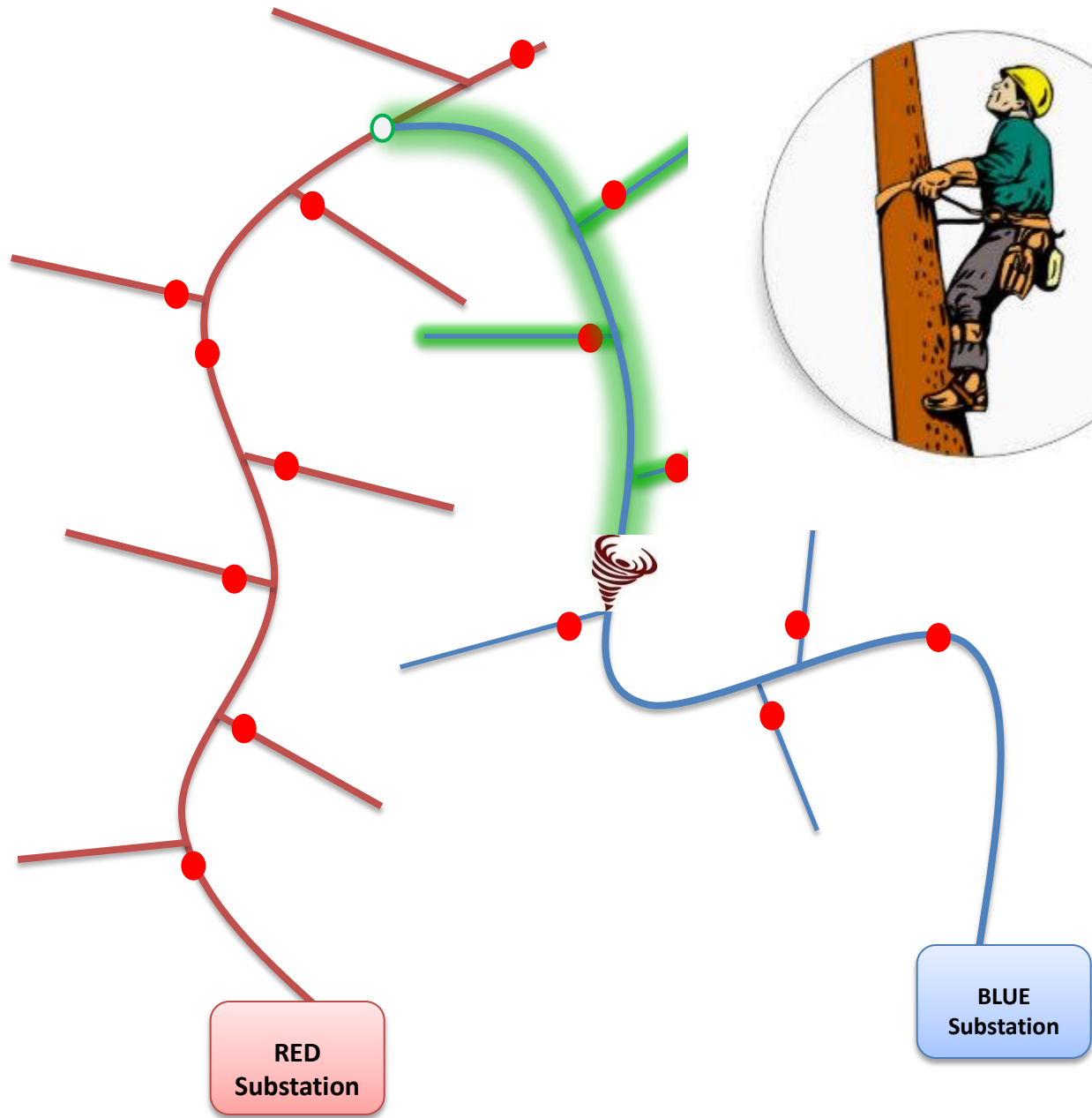
Smart grid technology enable better knowledge of state and more immediate And more precise control

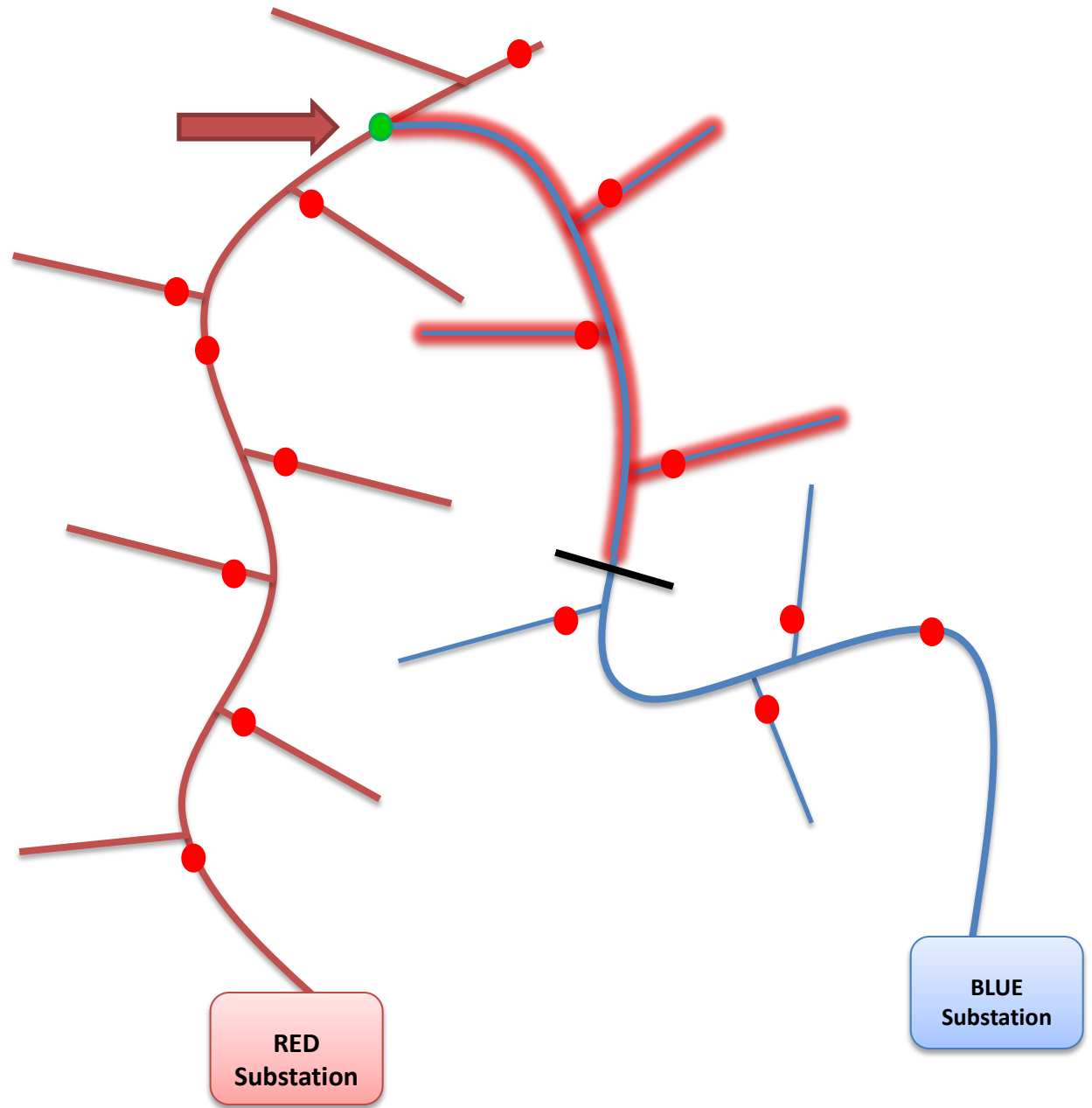


**RED
Substation**

**BLUE
Substation**

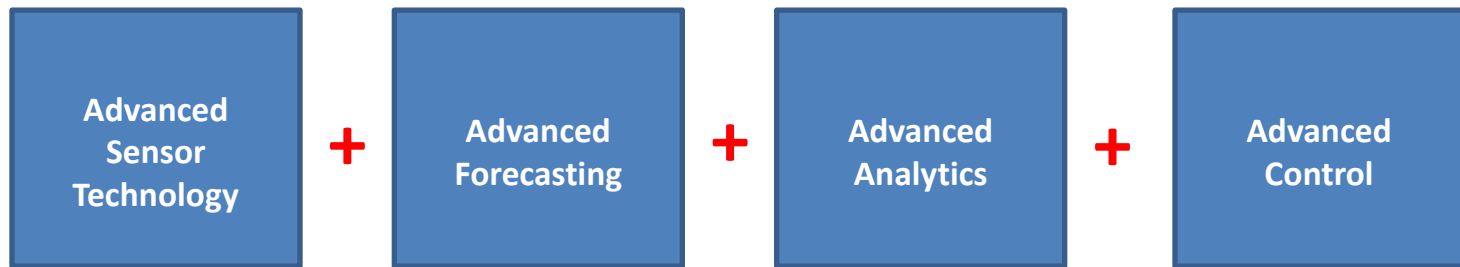






But what if simple back feeding is not enough?

Resiliency from



Apply all “smart grid technologies” in a coordinated way

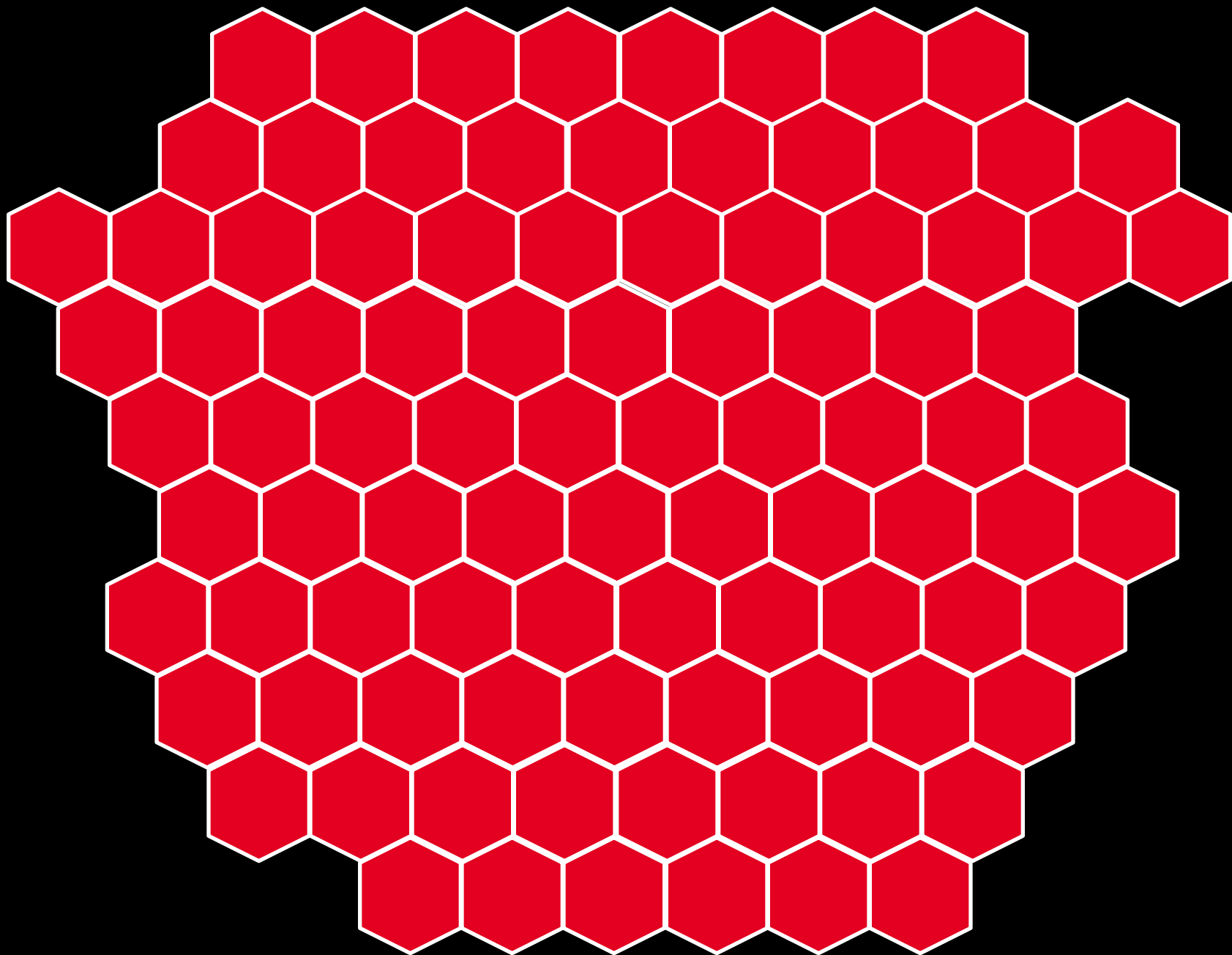
- Smart feeder switching
- Advanced sectionalization
- Rolling disconnects (down to meter level)
- Dispatchable backup generators
- Distributed energy
- Advanced Volt/VAR control
- Storage

.....

That's how the agile grid can work
on a feeder. How would it look at
a system level

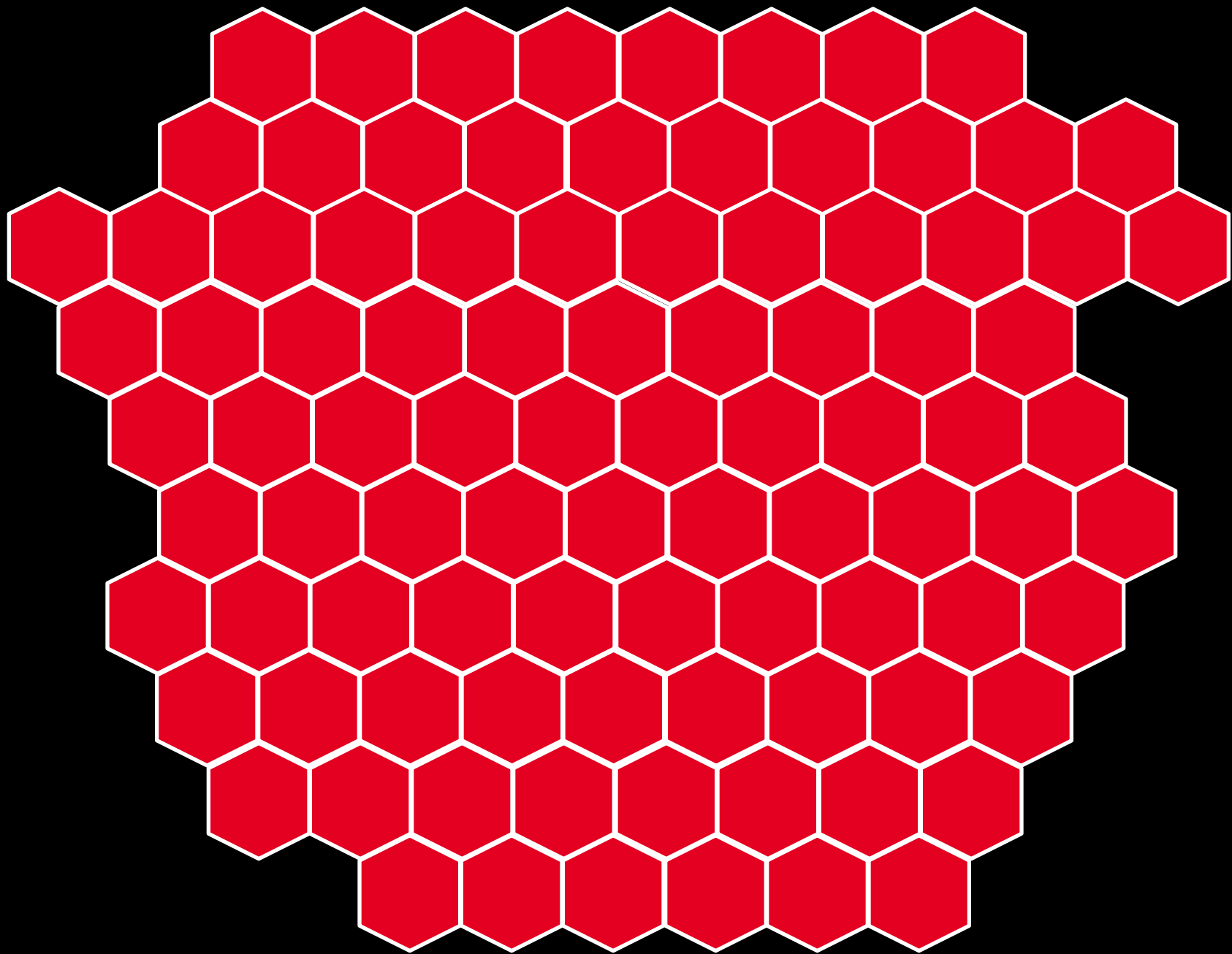
On a nice day, the
utility is running smoothly.

Everything is “Hot”

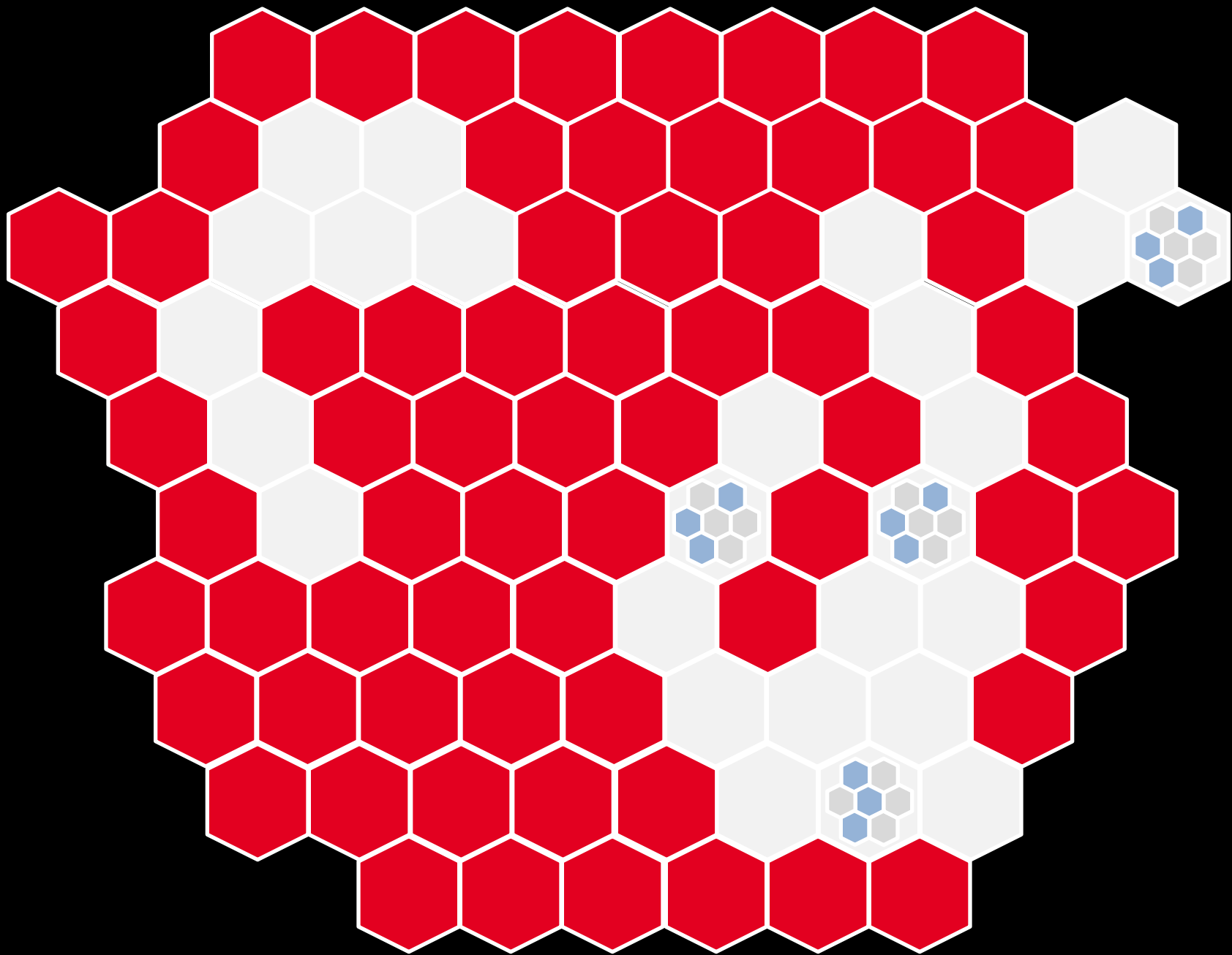


**A bad storm comes through
and some areas lose power**

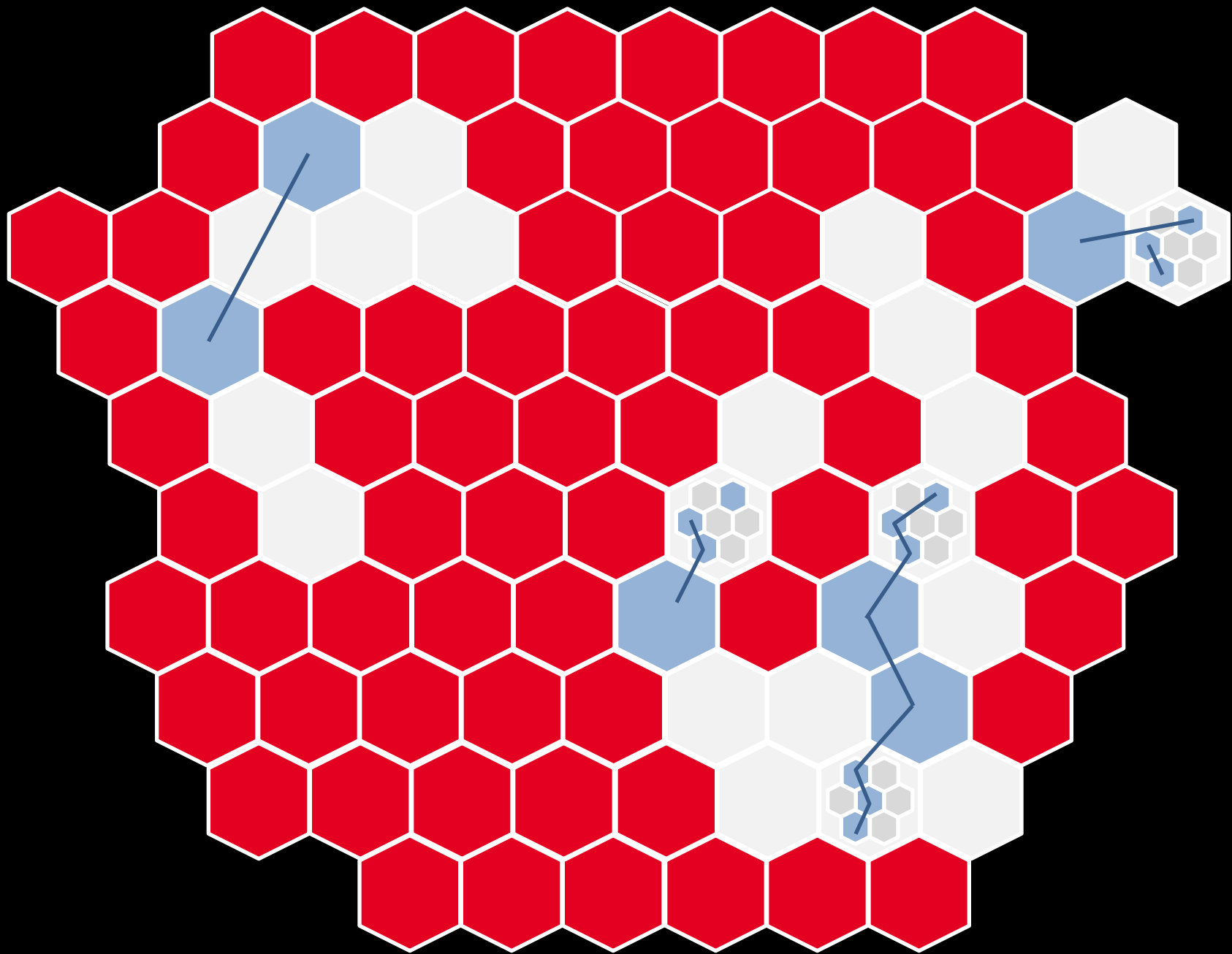




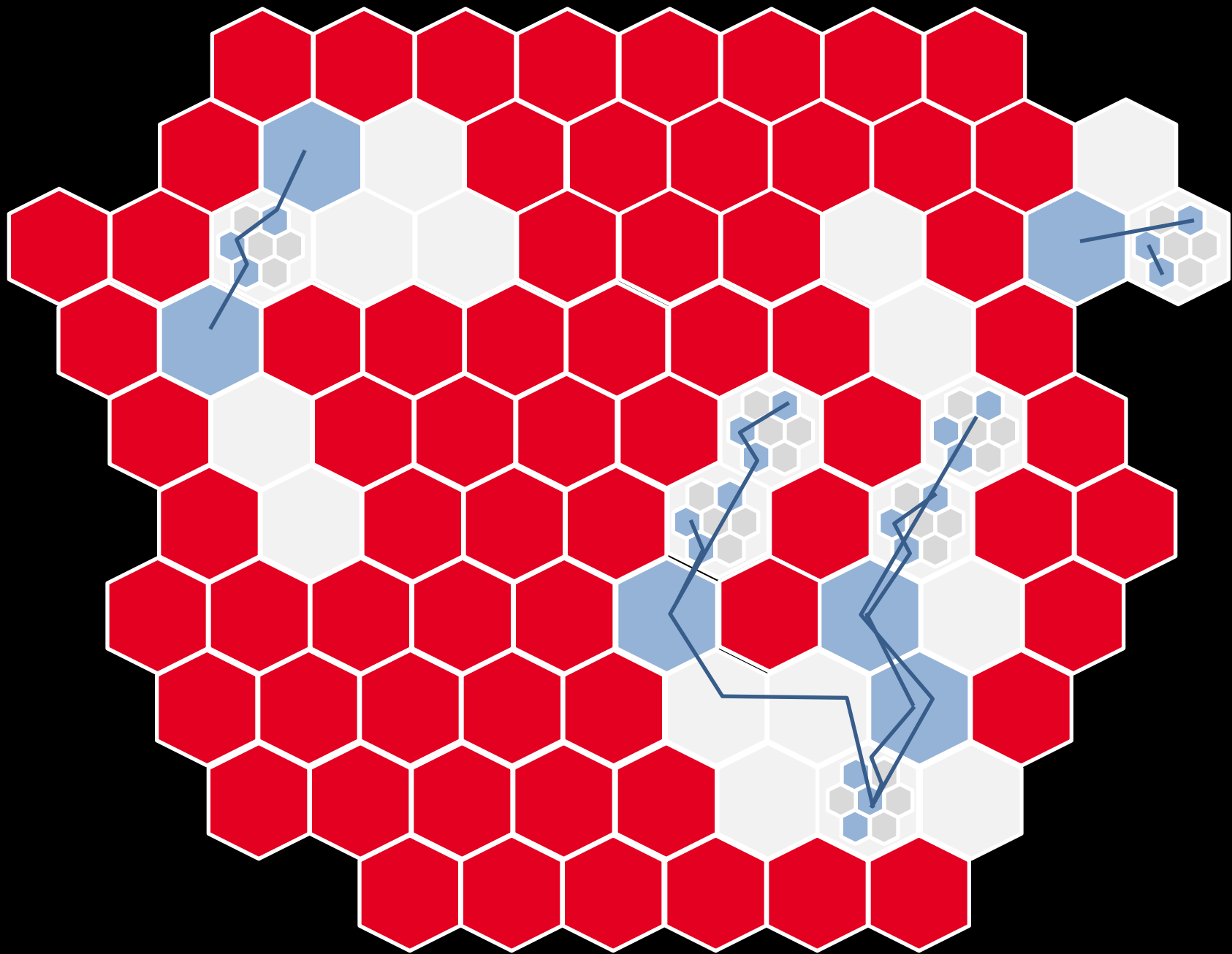
**But backup power,
distributed generation,
and stored energy allow
some areas to island
and continue operation...**



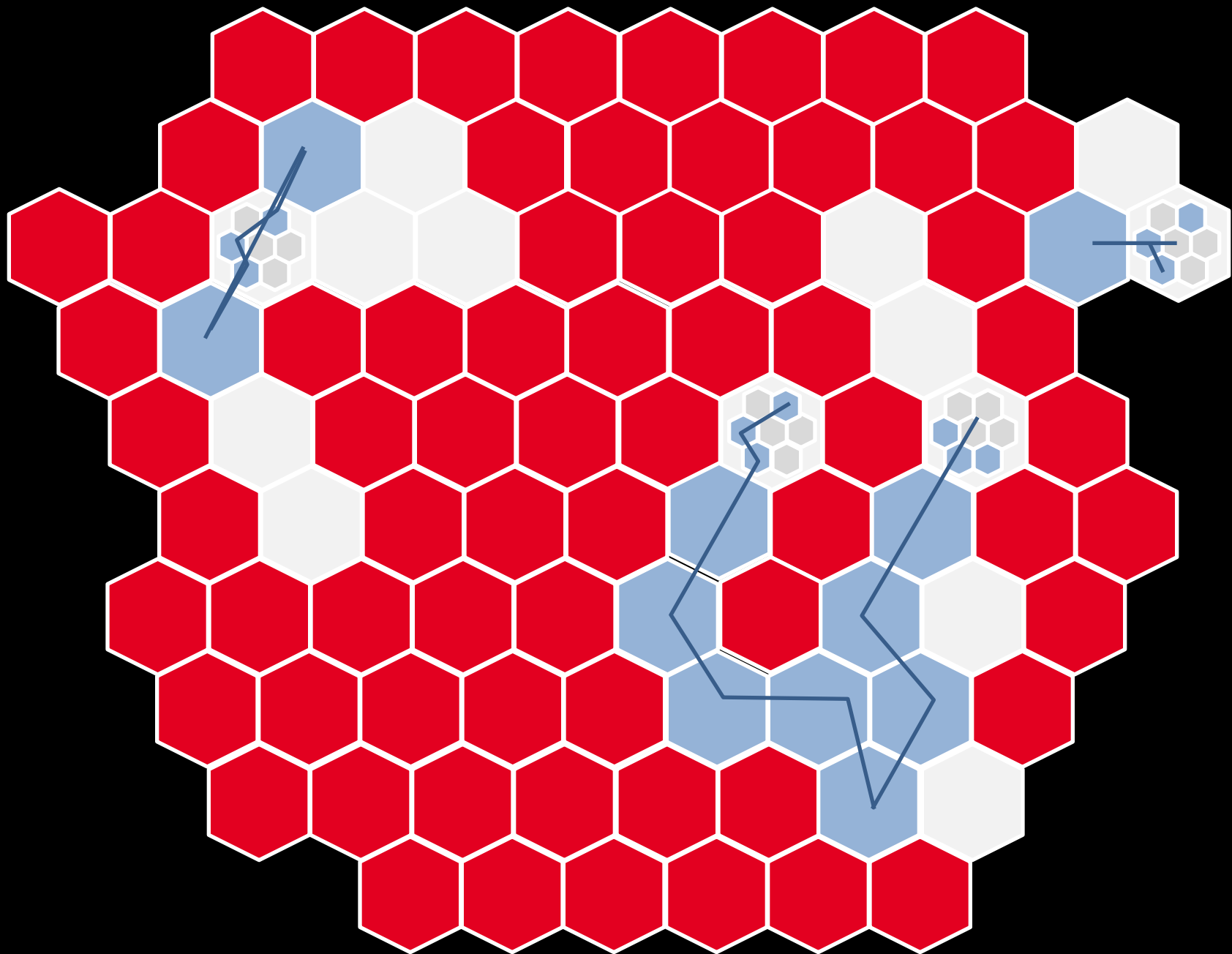
Smart control systems allow
the islands to network



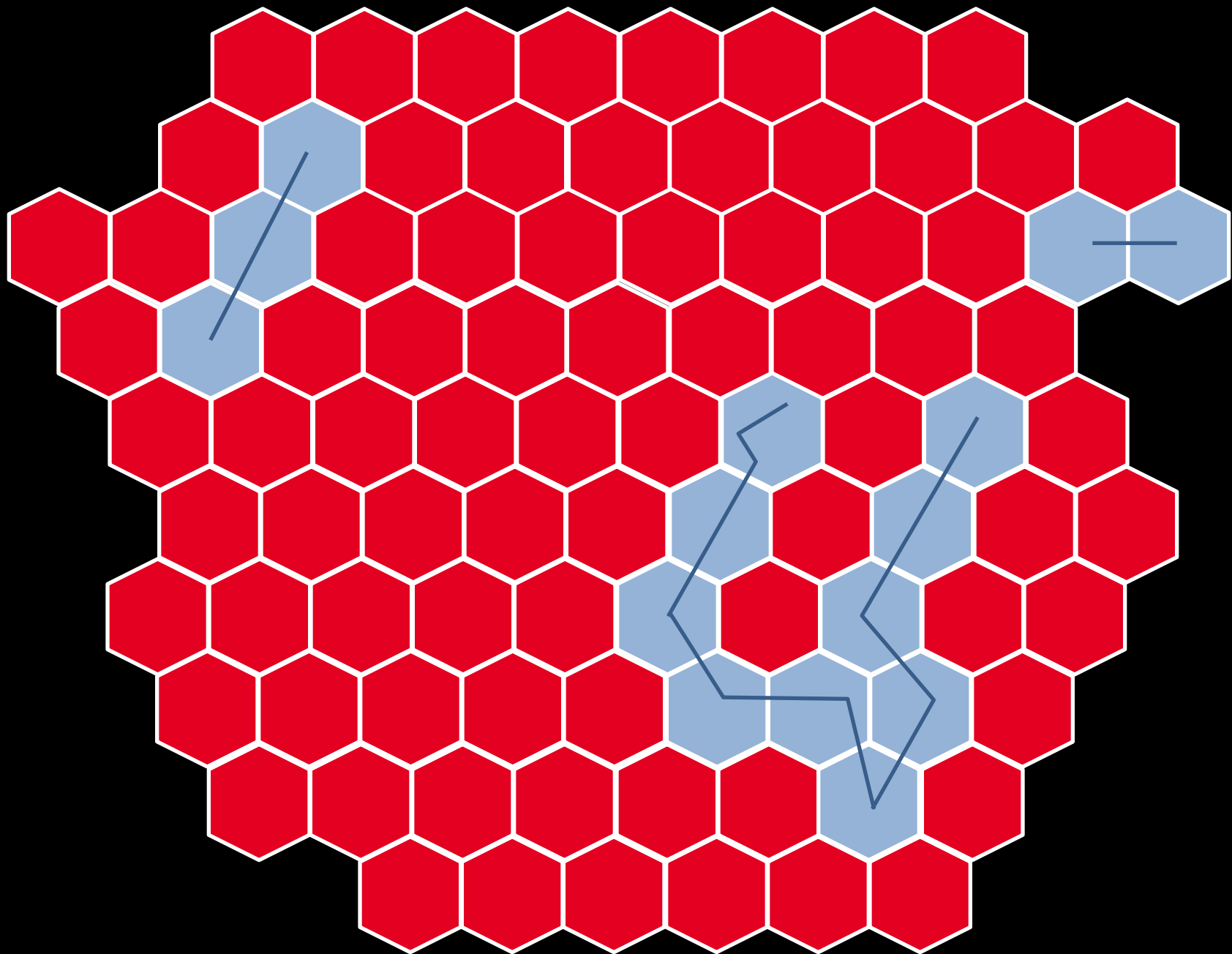
This may allow some power to be restored in additional areas as the utility works to bring dark areas on line



Soon, everyone has power

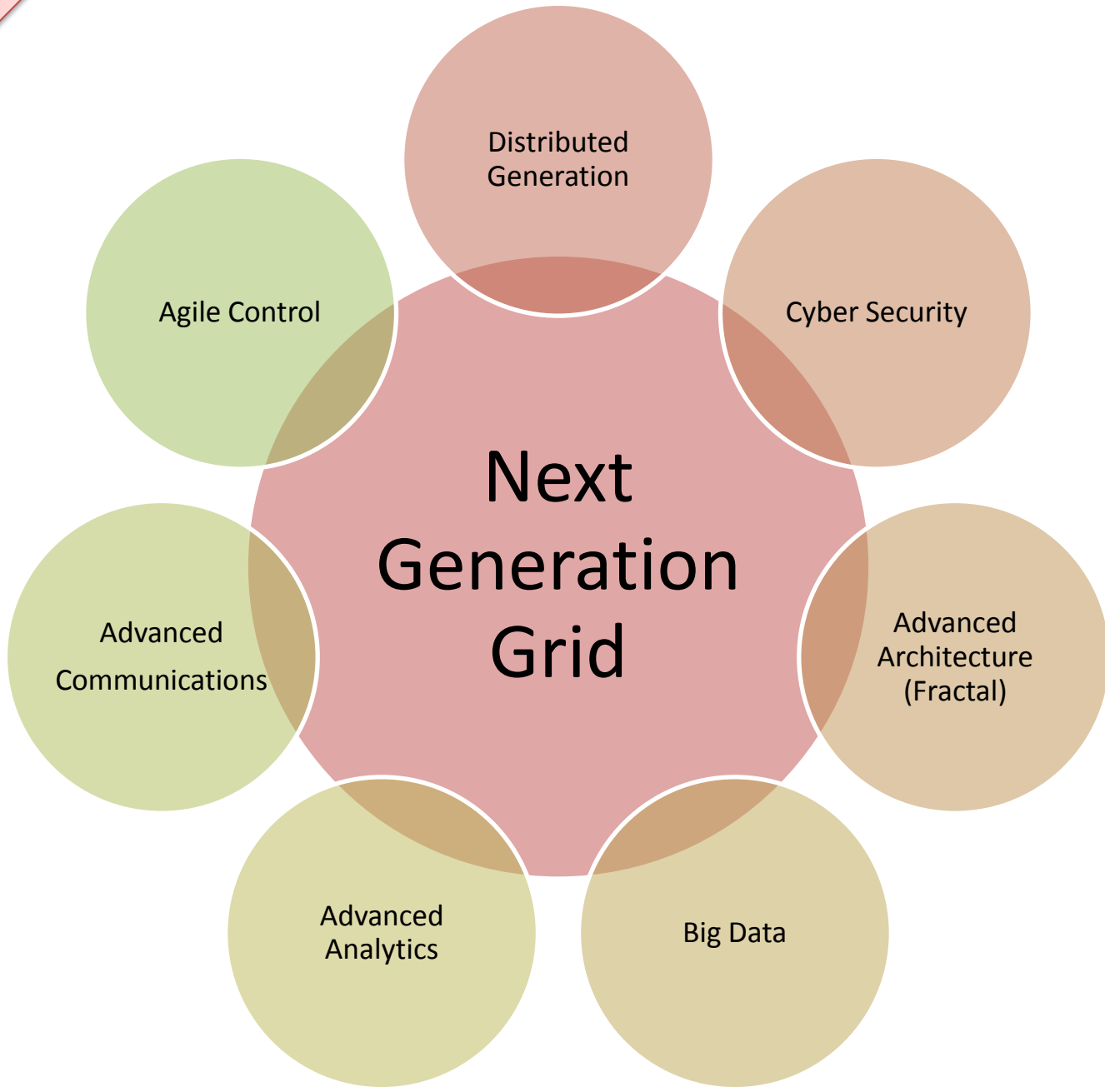


The smaller grids
reconnect with the utility



OK, it is an interesting
concept, but how does it
work?

FOUNDATIONS



FOUNDATIONS

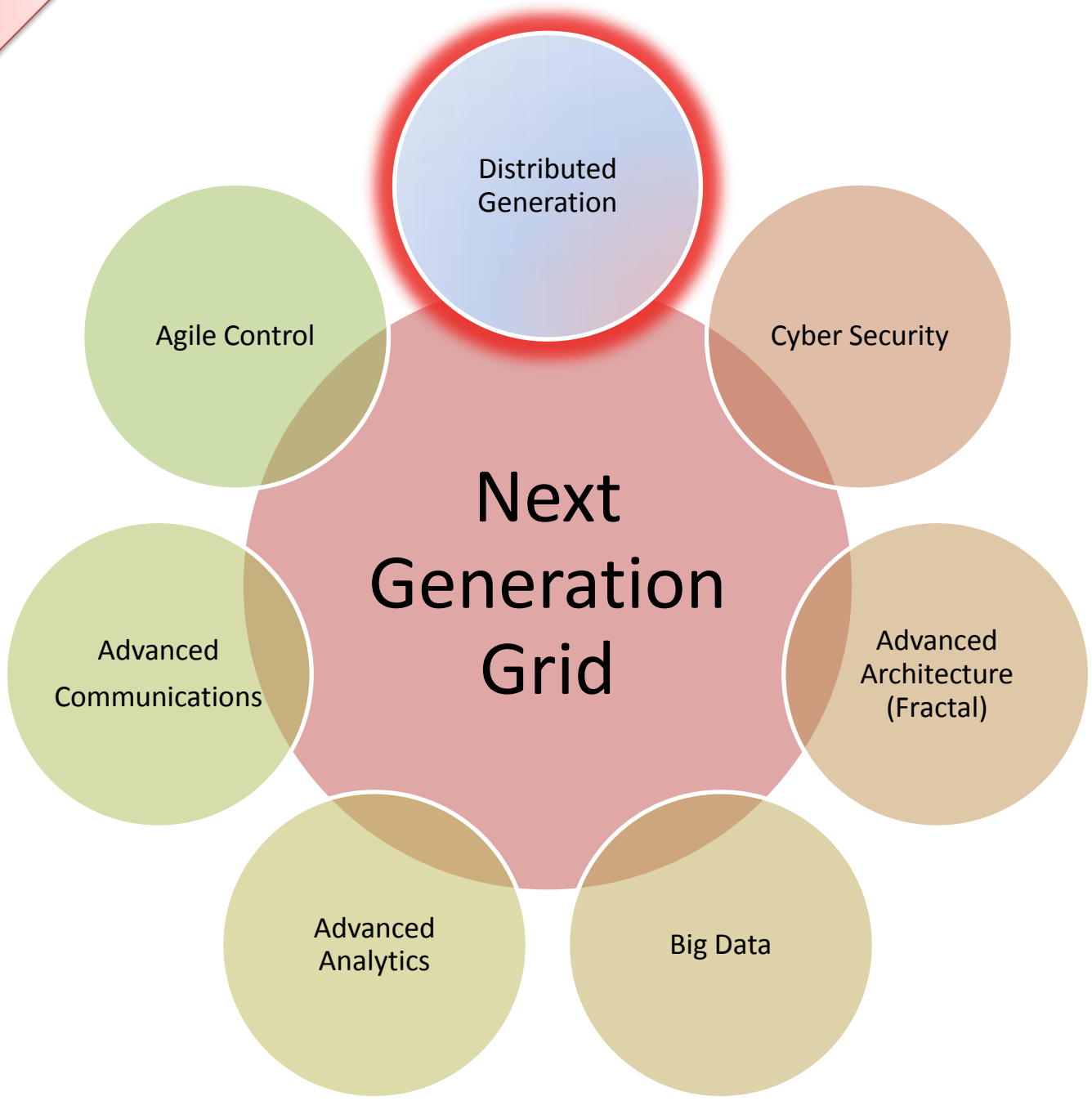
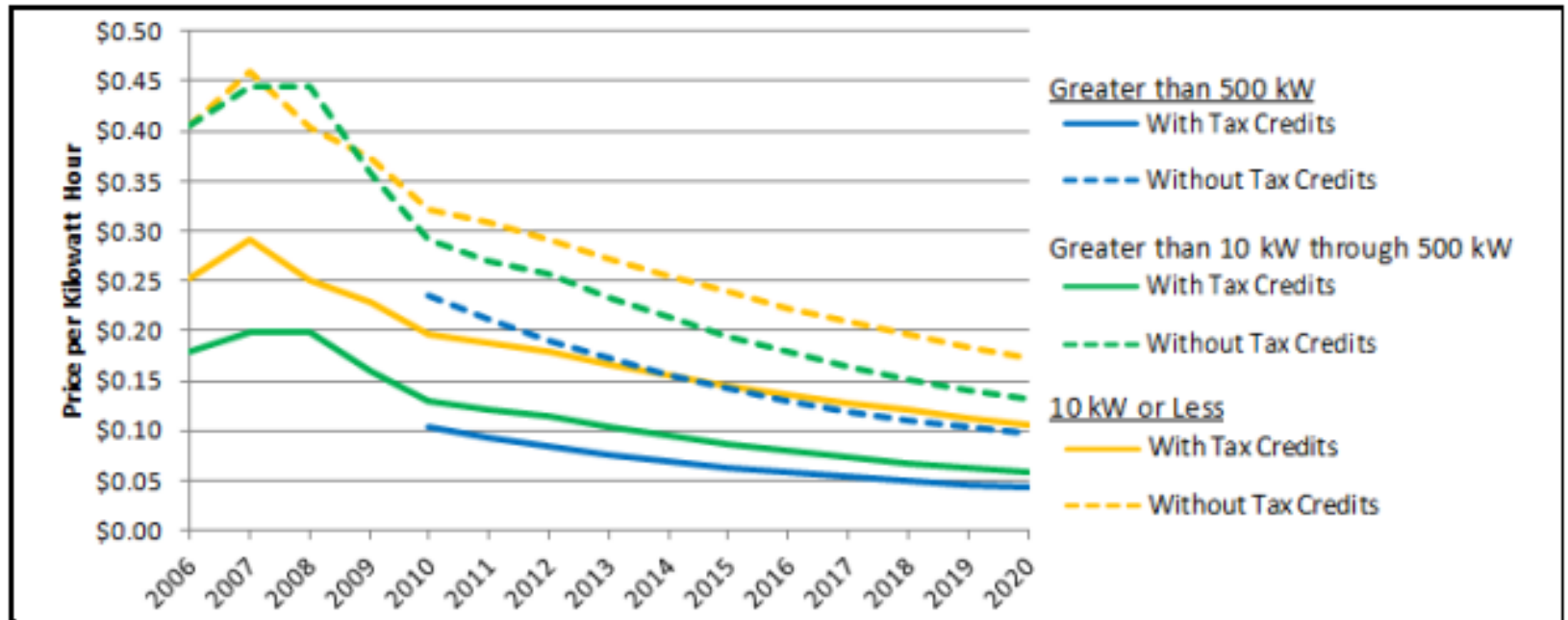






Figure 2. LCOE Trend Lines of Solar PV in North Carolina from 2006-2020.



Source: NREL, 2010

DIY Always Wins

Driving a car

Writing a report

Booking a flight

bing

off the grid house



bing

off the grid house

150,000,000 RESULTS

150,000,000 results

[Green Homes For Sale - Find a Green](#)

greenhomesforsale.com/off-the-grid-homes.php

OFF THE GRID: The term **off-the-grid** (OTG) or **off-grid** refers to living in a self-sufficient manner without reliance on one or more public utilities.

[What Do Off Grid Homes Look Like? Here are 5 Examples : ...](#)

www.treehugger.com/.../what-do-off-grid-homes-look-like-here-are-5...

So we know what it takes to live **off grid** and how you generate **off grid** power, but what does living **off grid** look like? It might be a surprise to some, but some **off** ...

Nellis Air Force Base Solar

DOD Goal: 25X25 – 25% renewable by 2025

U.S. Army committing \$7 billion



How to Build a \$1000 Fusion Reactor in Your Basement

Admittedly, the project is a little dangerous—not because of a few little fusion reactions but because of the the very flammable gas and voltages high enough to instantly kill you.

by Amy Barth; Illustration by Steve Karp

From the **Extreme Universe special issue**; published online March 2, 2010



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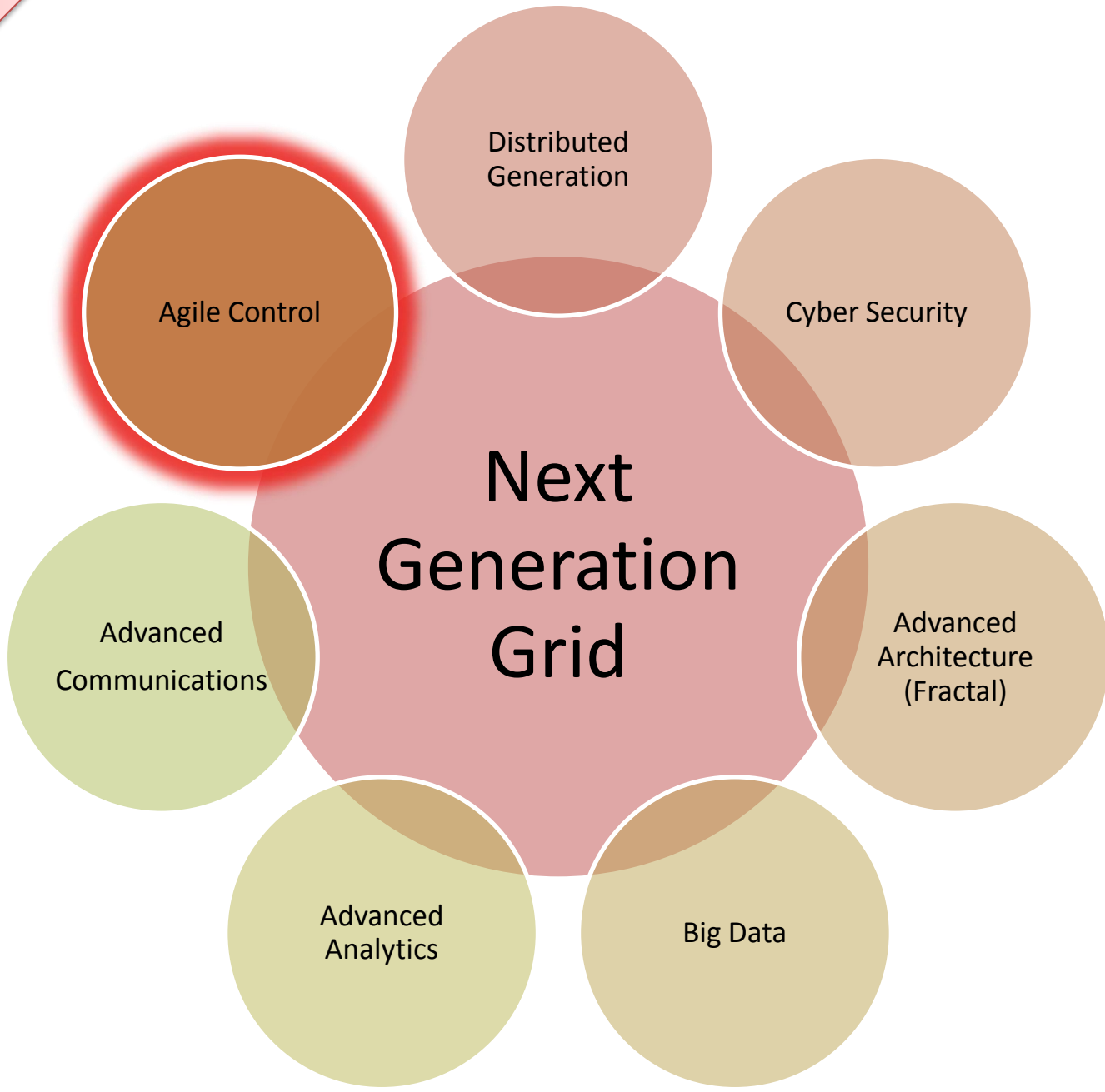
A A A

This article is a sample from DISCOVER's special Extreme Universe issue, available only on newsstands through March 22.

Most college freshmen fill their dorm rooms with clothes fusion reactor. But Vanderbilt University drew the line: No was housed in a nearby laboratory.



FOUNDATIONS



Distributed Generation

Agile Control

Cyber Security

Next Generation Grid

Advanced Communications

Advanced Architecture (Fractal)

Advanced Analytics

Big Data

Smart Appliances

Center of Control?



Estimates of 45 Million Smart Appliances by 2020

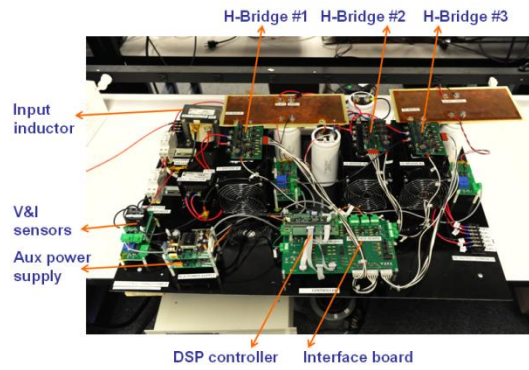
Navigant Sept 2012



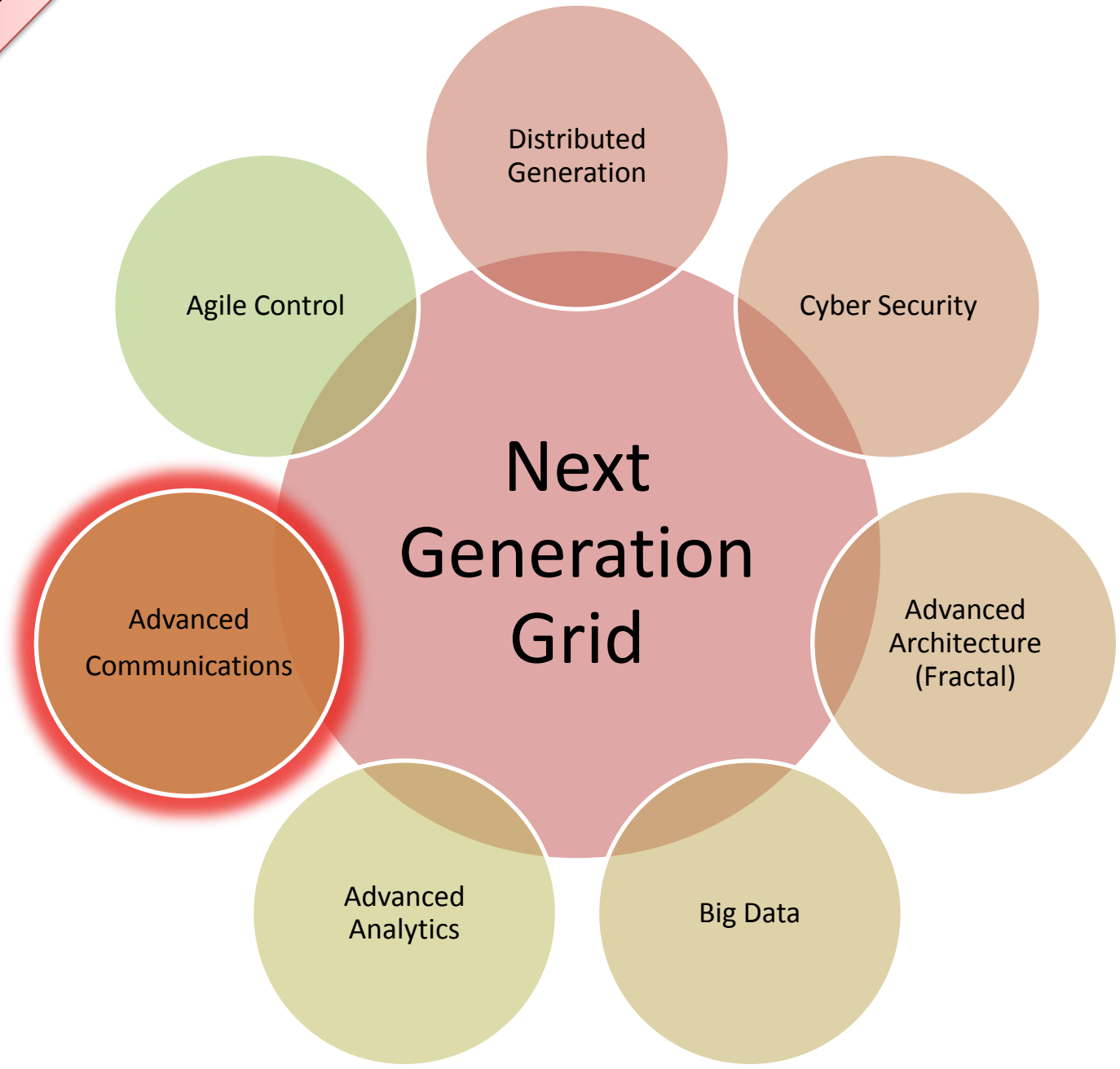
control

make smarter energy choices with
Brillion-enabled appliances





FOUNDATIONS



Distributed Generation

Agile Control

Cyber Security

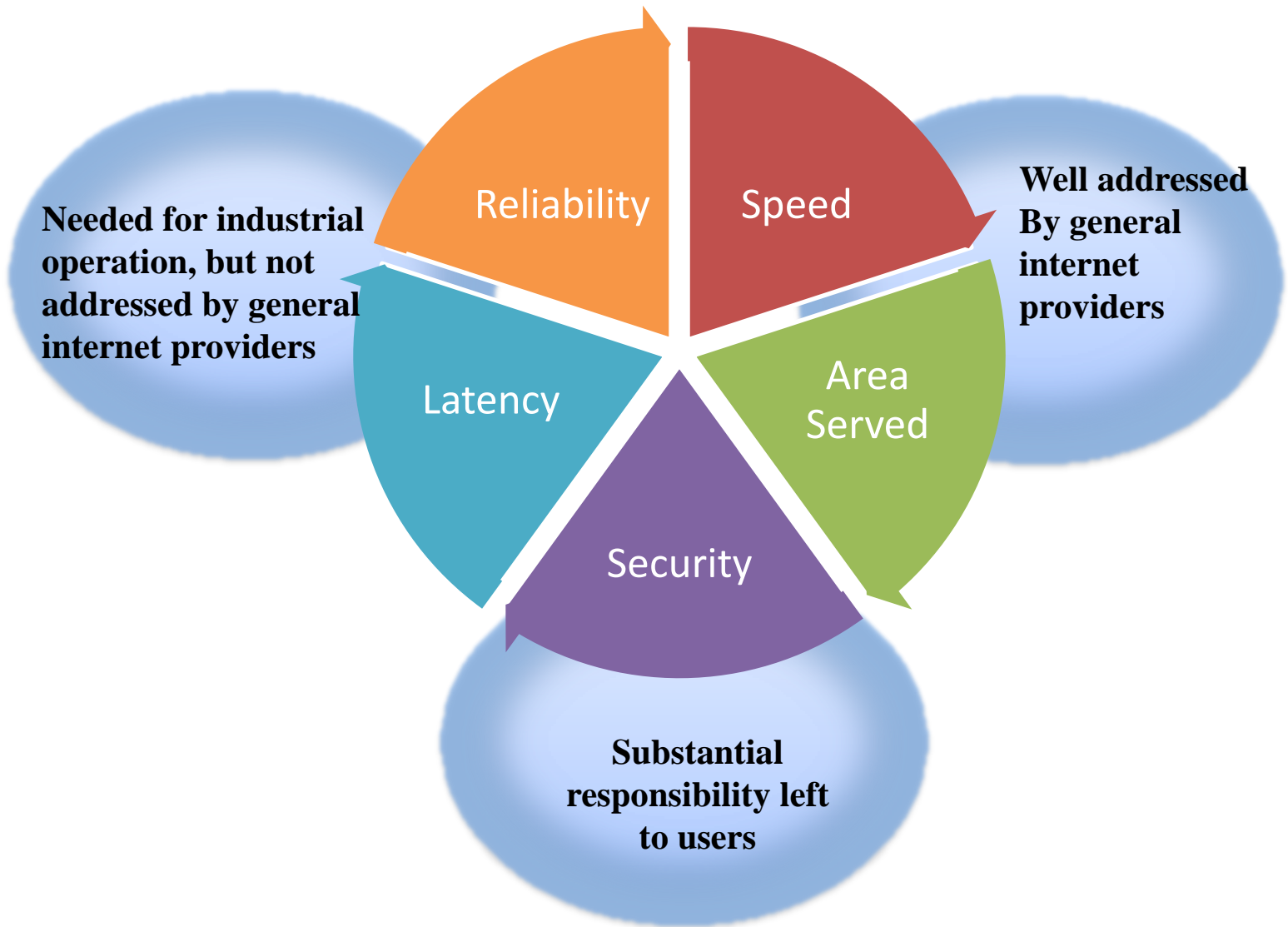
Next Generation Grid

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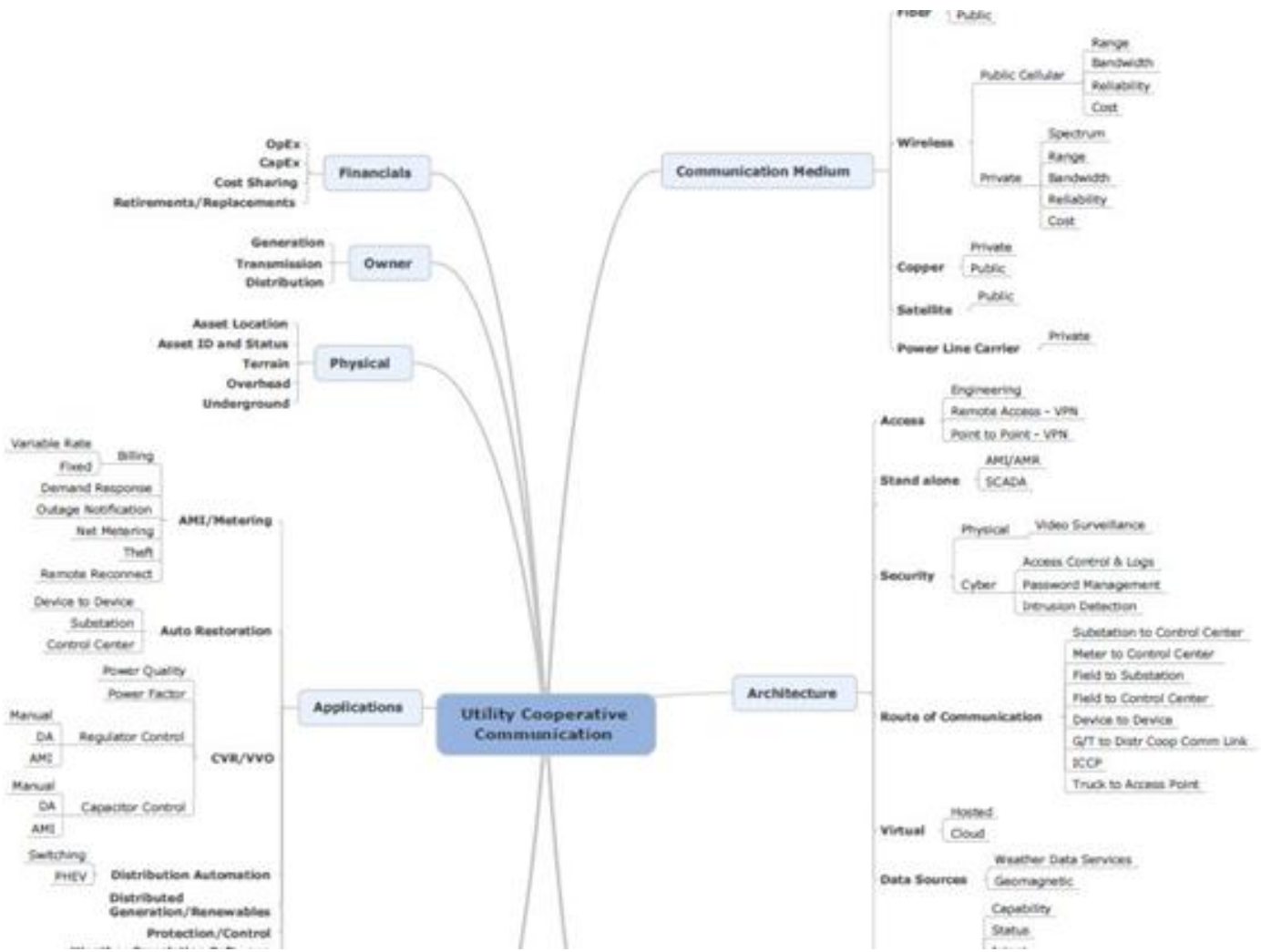
Key Organizations for the Trustworthy Internet

- Internet 2
- Internet of Things
- Industrial Internet

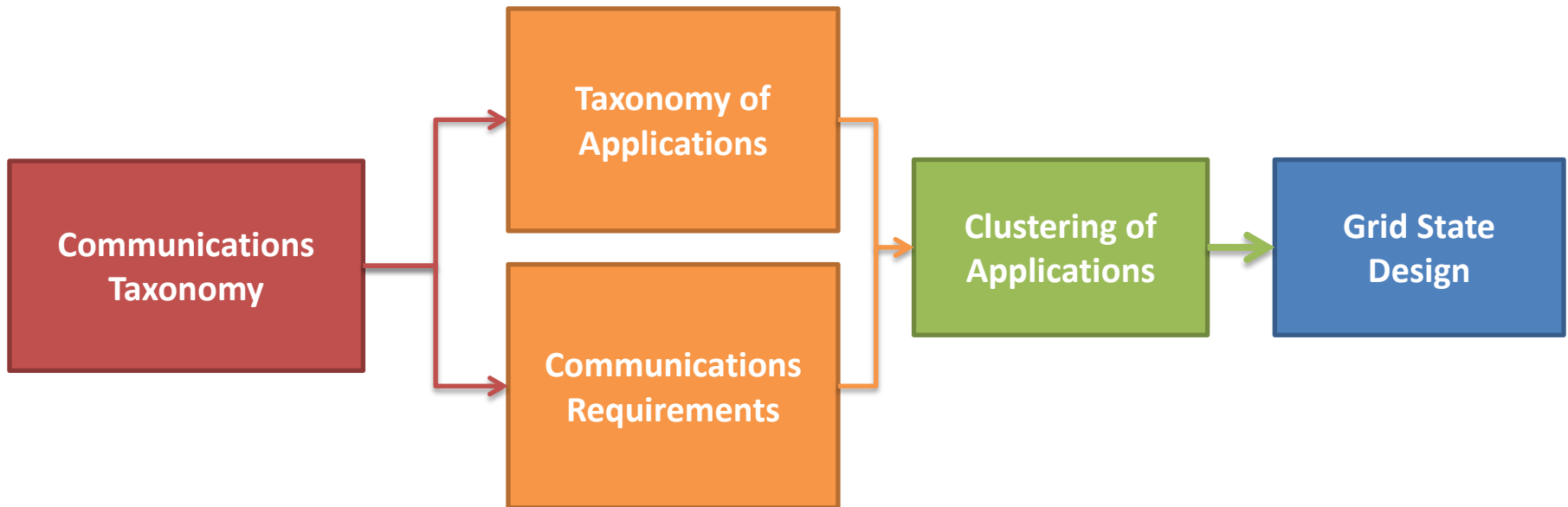
Internet 2



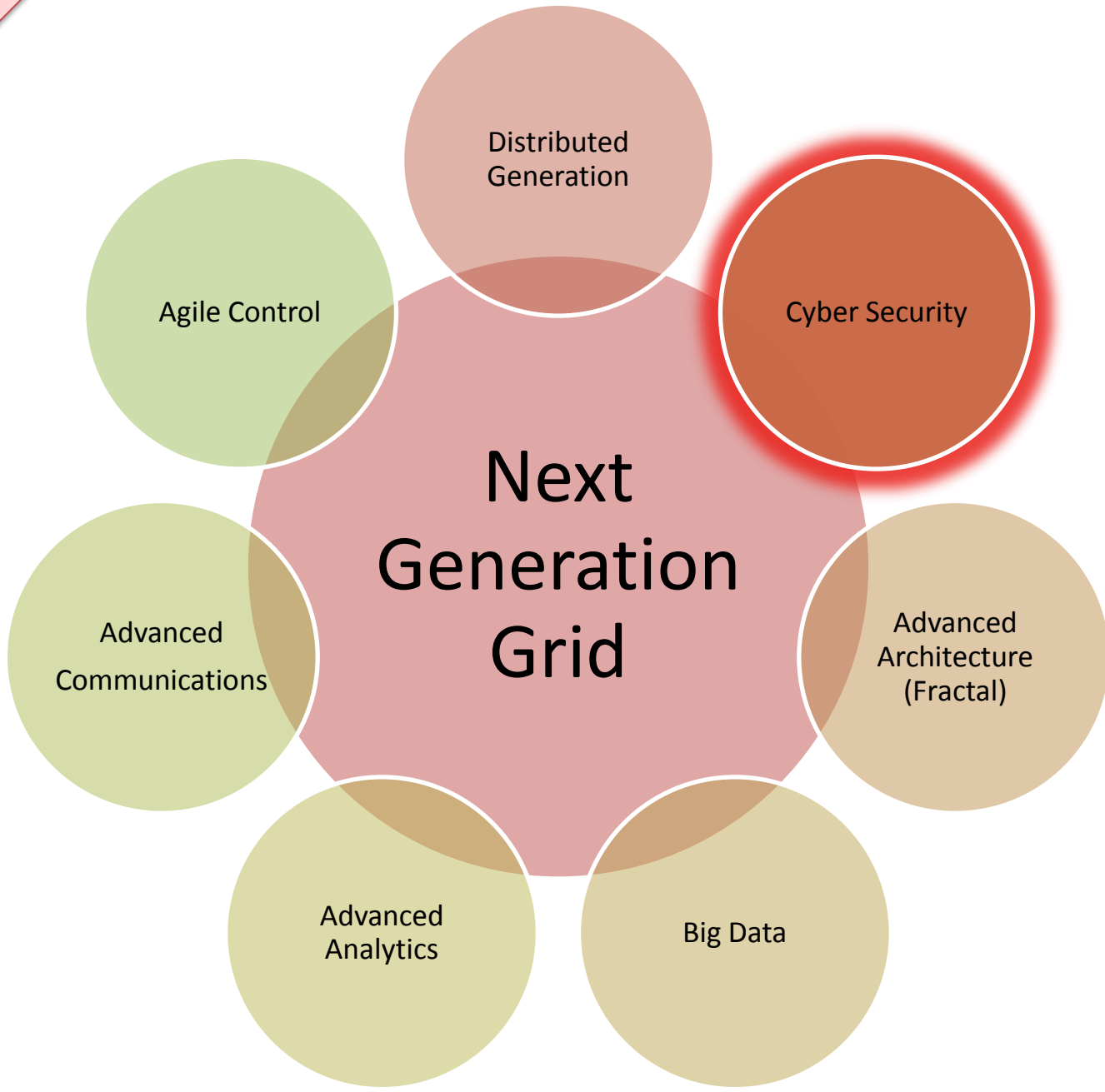
Taxonomy of Communications



Building on the Taxonomy



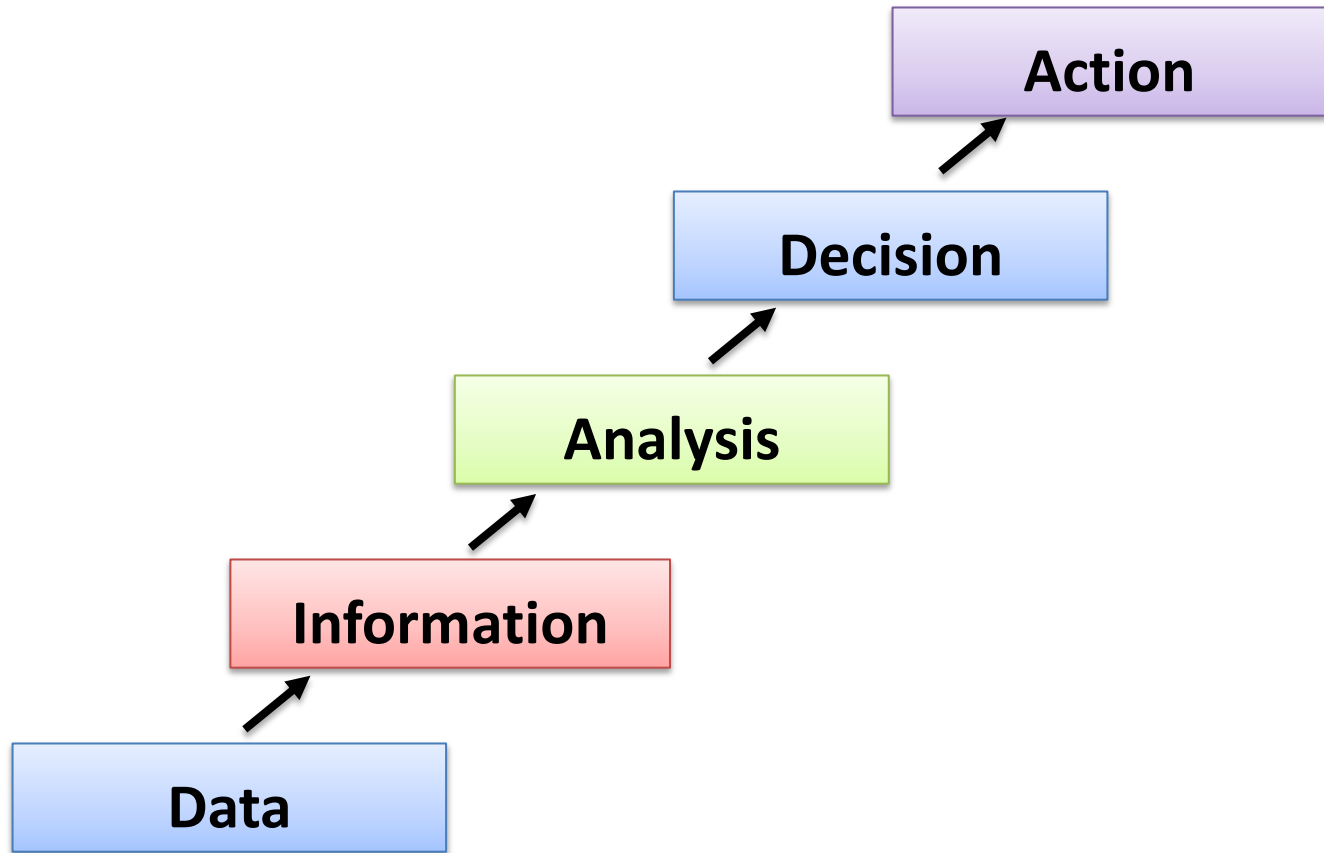
FOUNDATIONS



What is non-prescriptive cyber security and why do we need it?

- Prescriptive cyber security requires the user to identify the characteristics of suspicious communications
- Non-prescriptive is the opposite
- Prescriptive Security requires:
 - Knowing the threat
 - Knowing the system being protected
 - Having updates developed diligently
 - Knowledgeable users
 - Maintaining systems continuously
- There have been failures in all of the above

Abstraction Model



Action

- Host-based software defined network
- Server-based software define networks

Decision

- Predefined decision trees
- Contingency modeling
- Power flow analysis

Analysis

- Network Discovery
- Prescriptive checks
- Anomaly detection based using machine learning

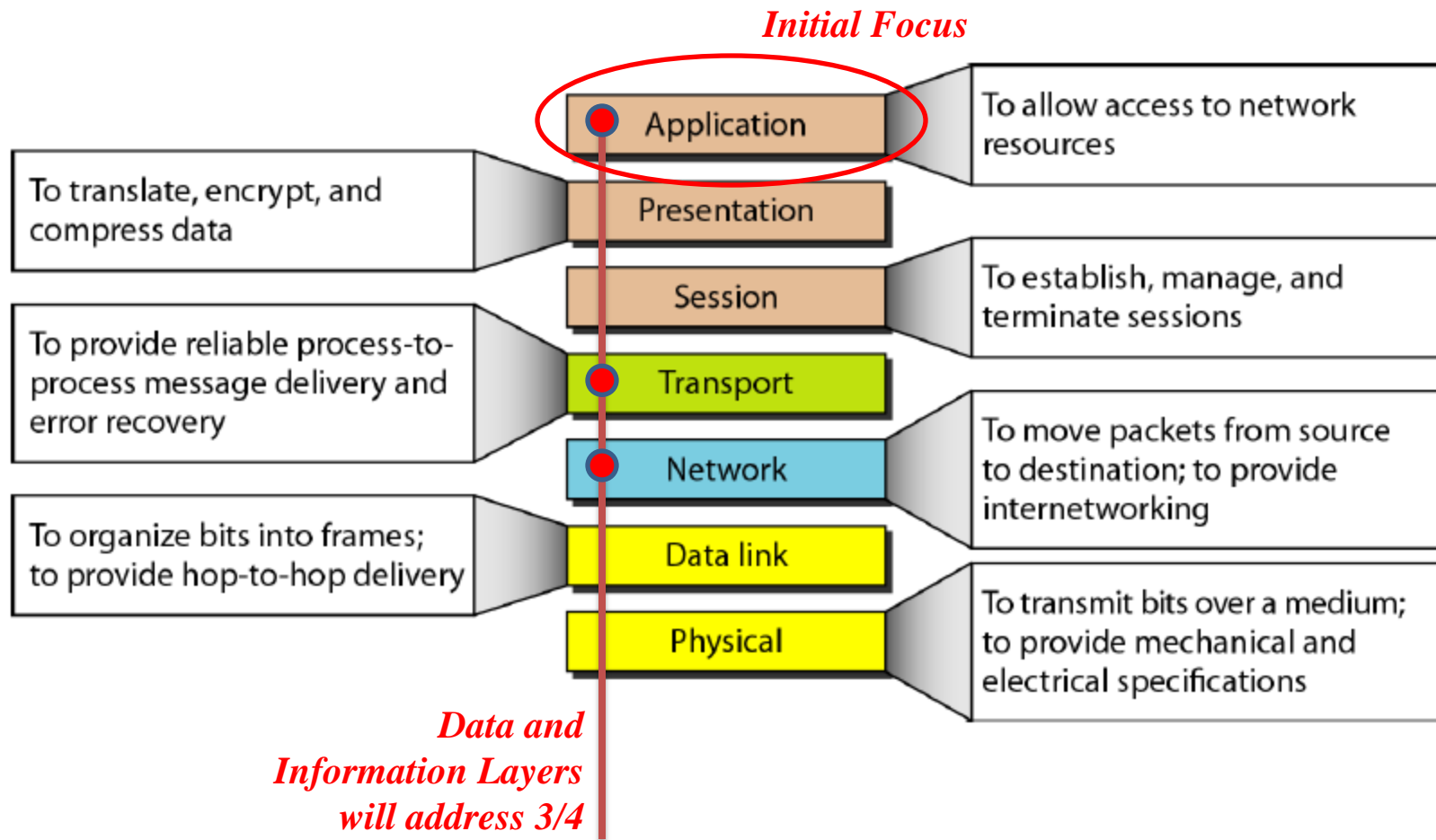
Database

- Comprehensive time series
- Derived views

Data Collection

- Passive add-on
- Dedicated in-line device
- Chip level
- Hardware in device
- Software

Focus of the Project in the OSI Stack



We are building three systems

The System

- *Centralized*
- *Cloud*

The system to test the system

- *Includes the development environment*

The system to maintain the system

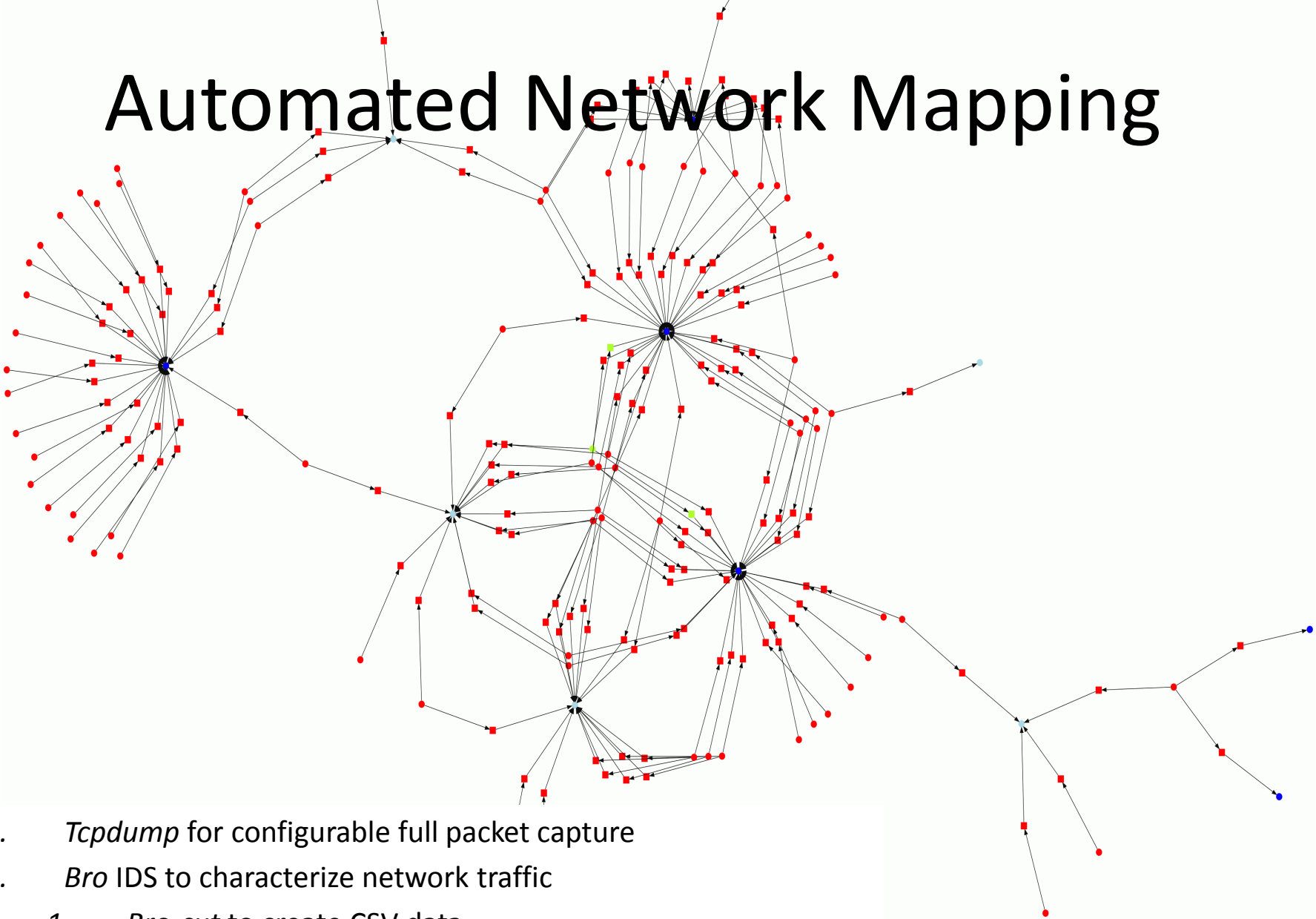
- *Updates*
- *Deployment management*

Full Packet Capture

- Data collection to support development
- Completely passive
- *NetOptics* TP-CU3 (copper)
- *Stealth* LPC-100G4
- Can also support fiber
- Open source software

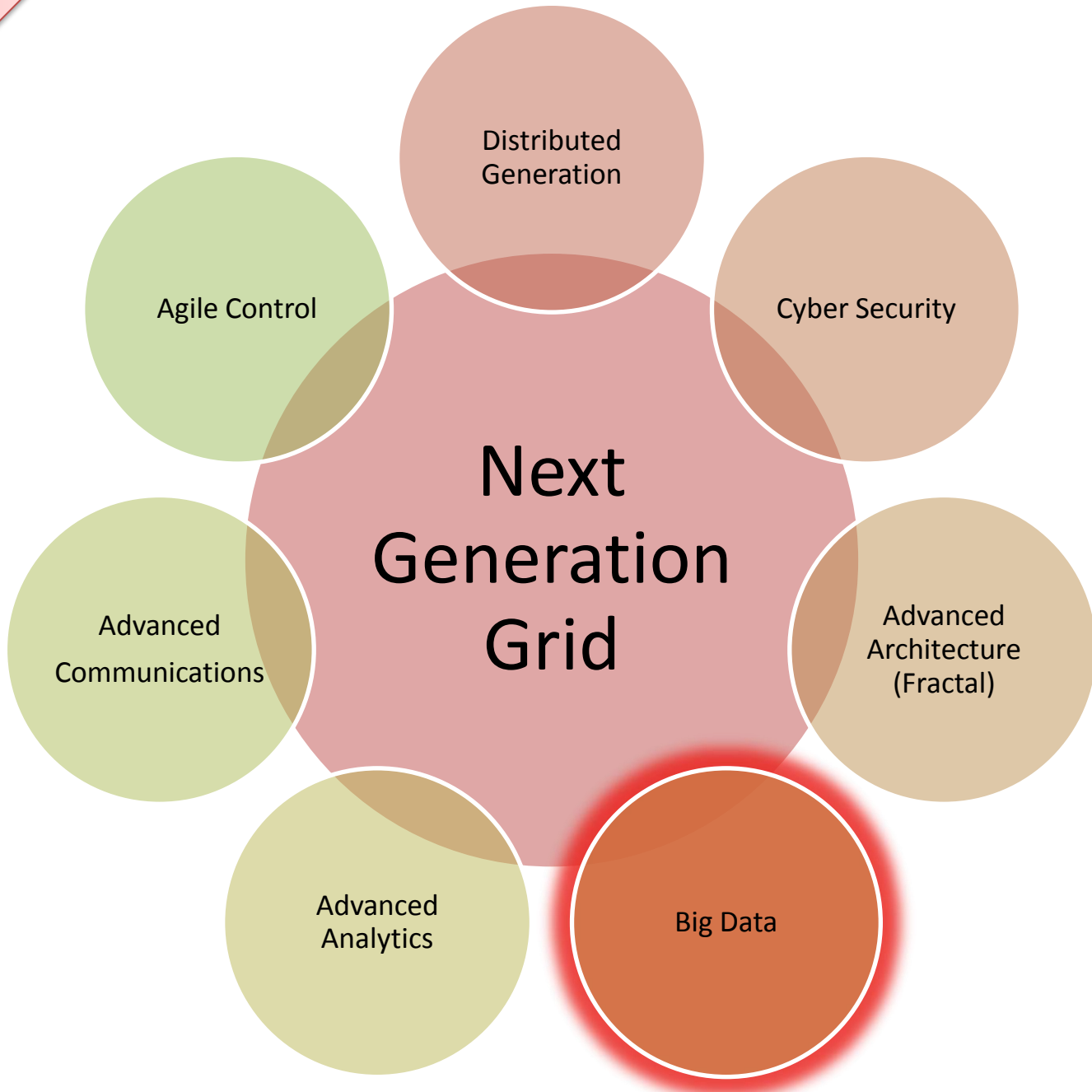


Automated Network Mapping



1. *Tcpdump* for configurable full packet capture
2. *Bro* IDS to characterize network traffic
 1. *Bro-cut* to create CSV data
 2. *Afterglow* to create graphviz files from CSV data
 3. *Neato* to draw graphs of observed network

FOUNDATIONS



The Fear

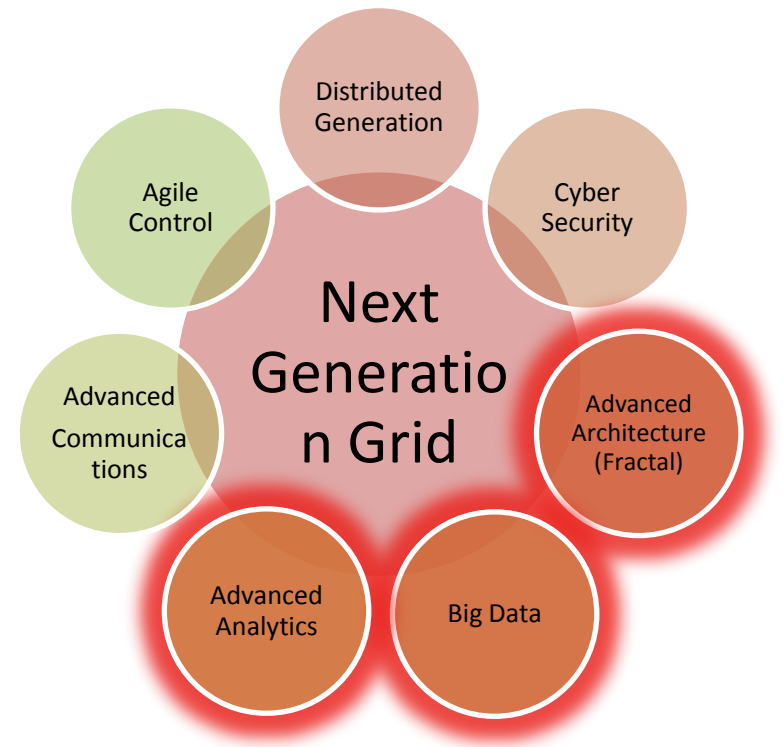
- EPRI: 10^4 more data
- IBM: 10^5 more data

Surprise!! Didn't Happen, but:



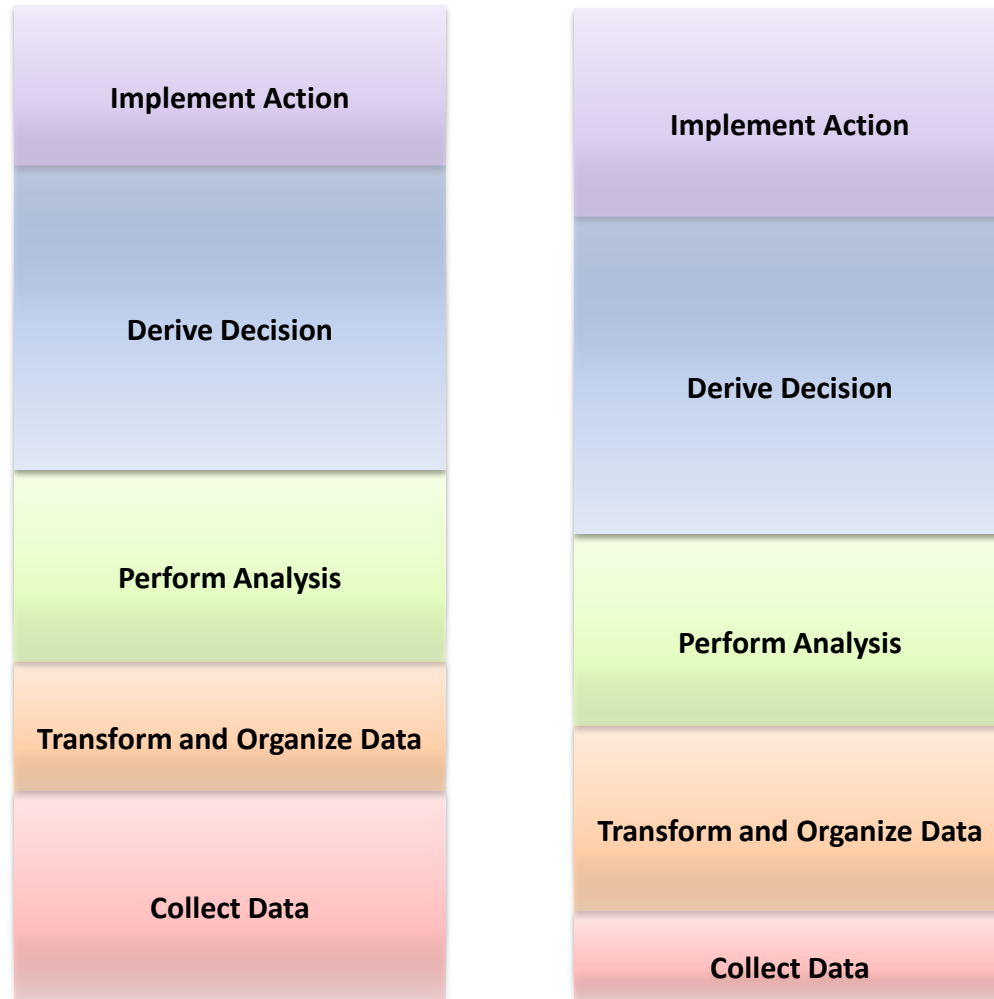
Issues

- Transportation bottleneck
- Reporting by exception
- 99.998% redundant information
- Building for the “Interesting Day”

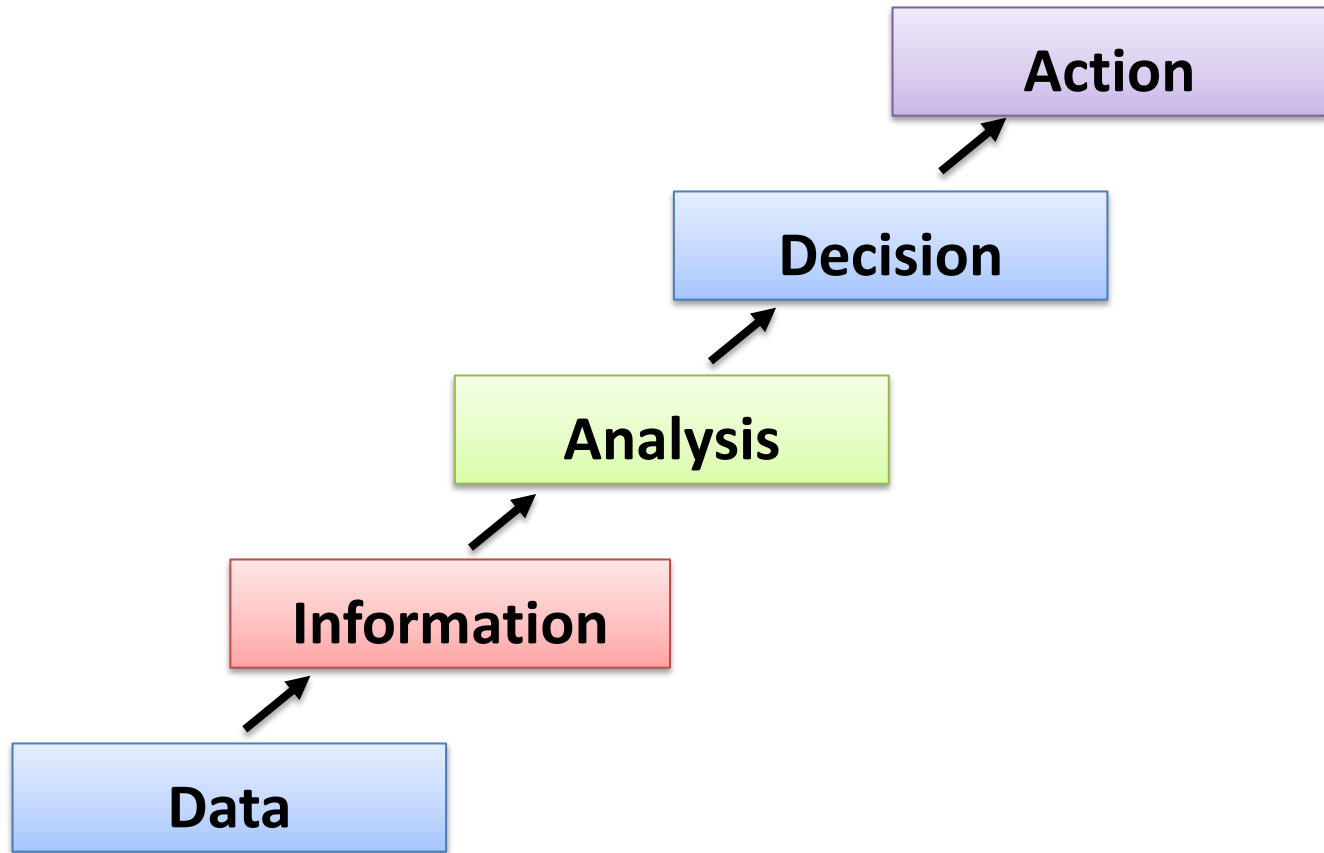


**THE SOLUTION TO THE DATA ISSUE
MUST BE ROOTED IN ARCHITECTURE**

All grid applications have the same basic structure



Abstraction Model



Typical Application Stack



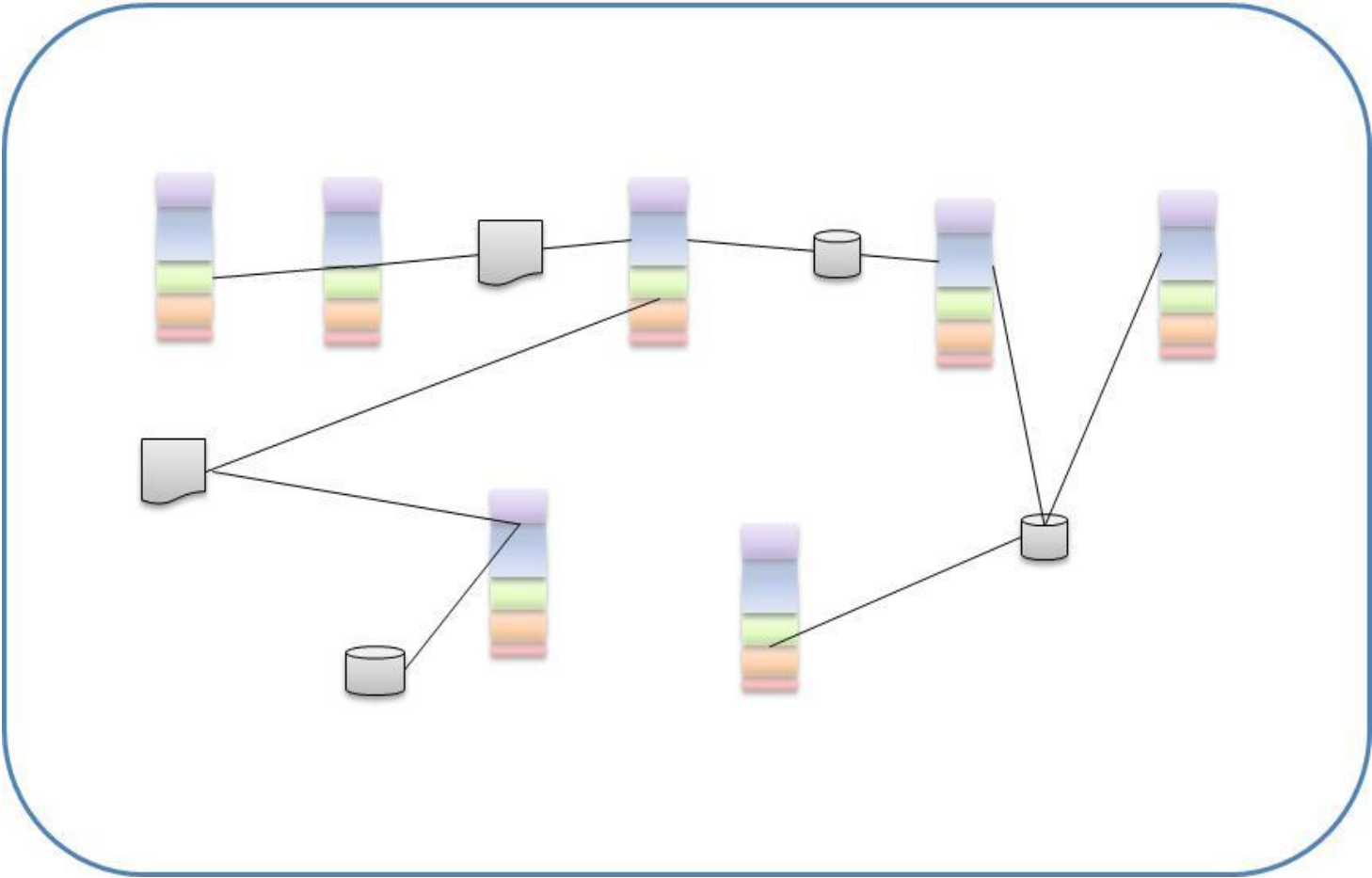
STAGE 1

“Architecture Free” collection of applications at a utility



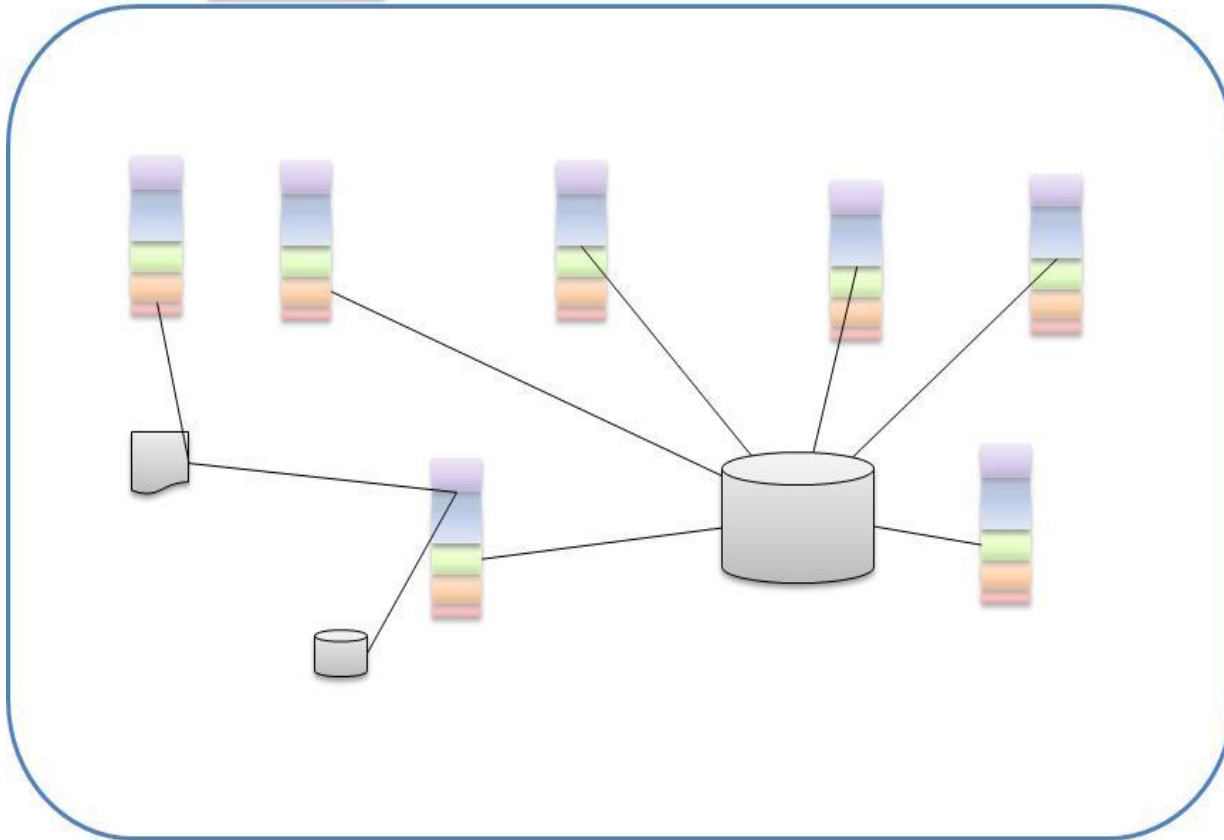
STAGE 2

“Point to Point Connectivity”



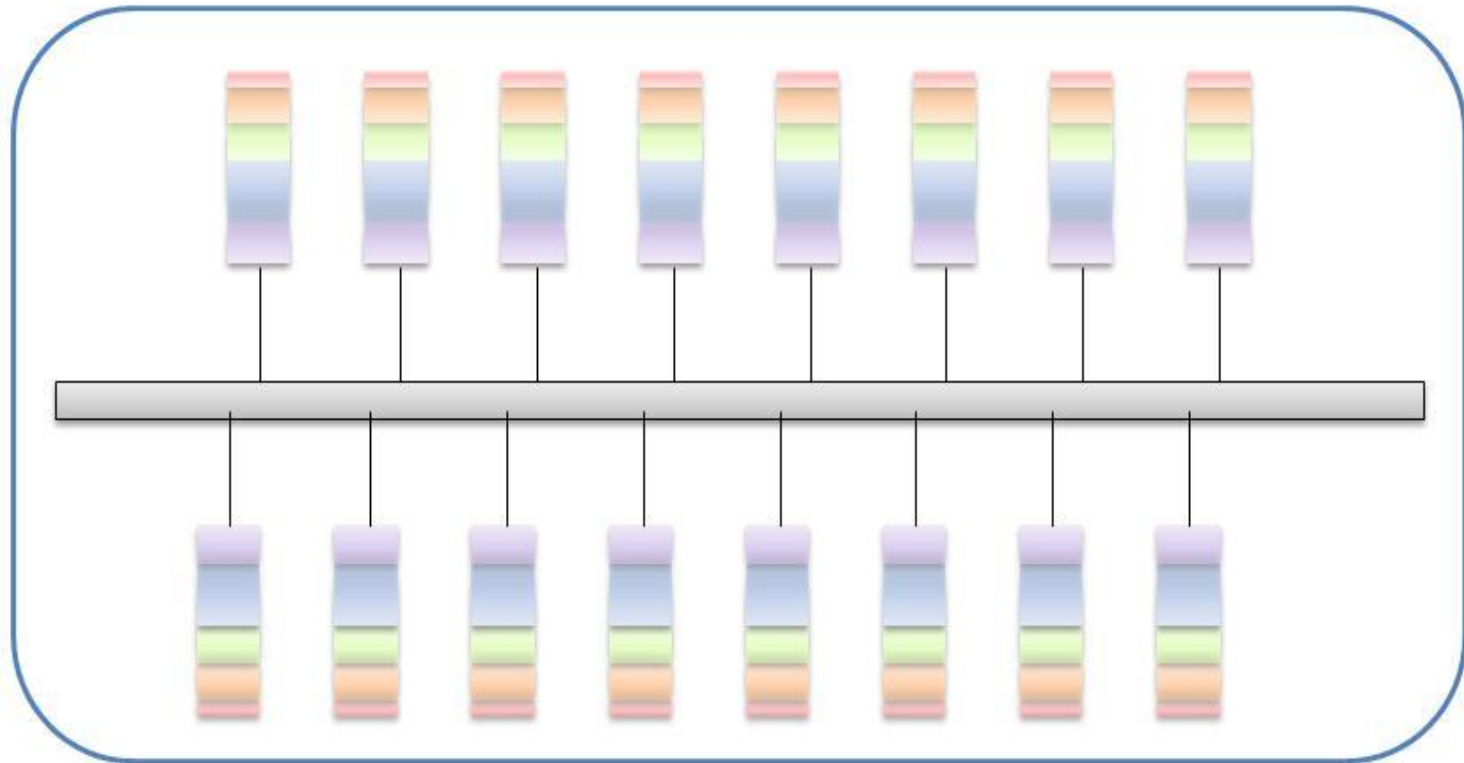
STAGE 3

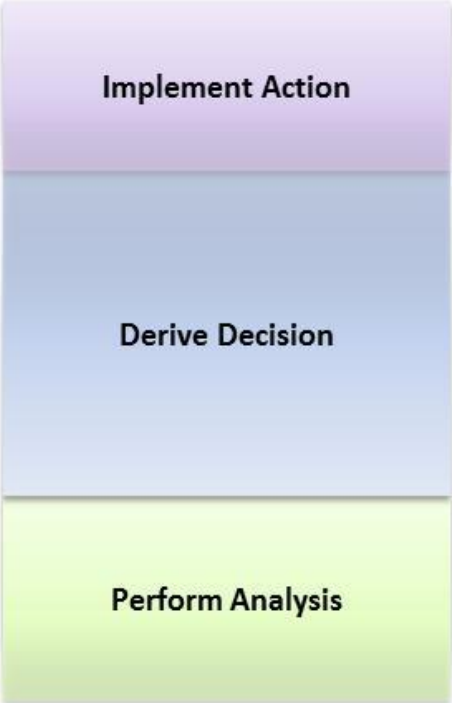
“Database Centered”



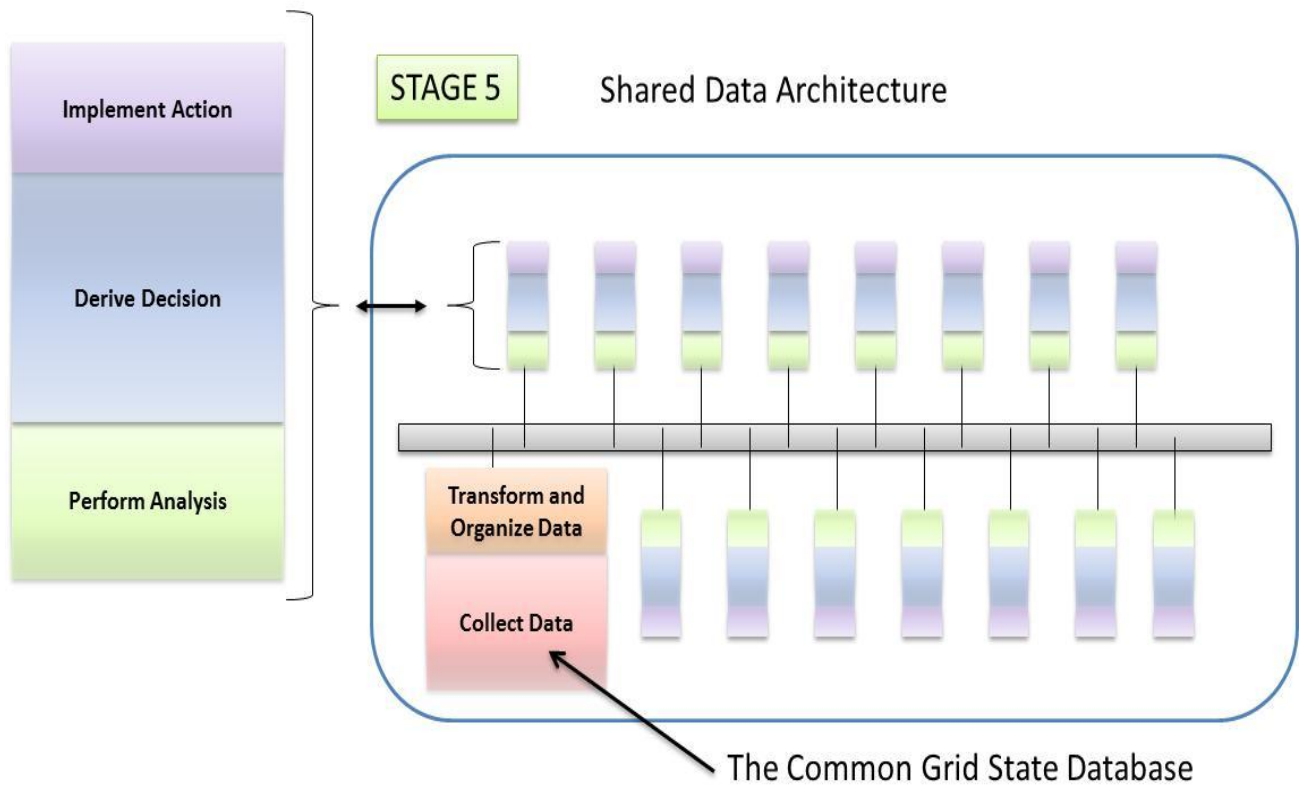
STAGE 4

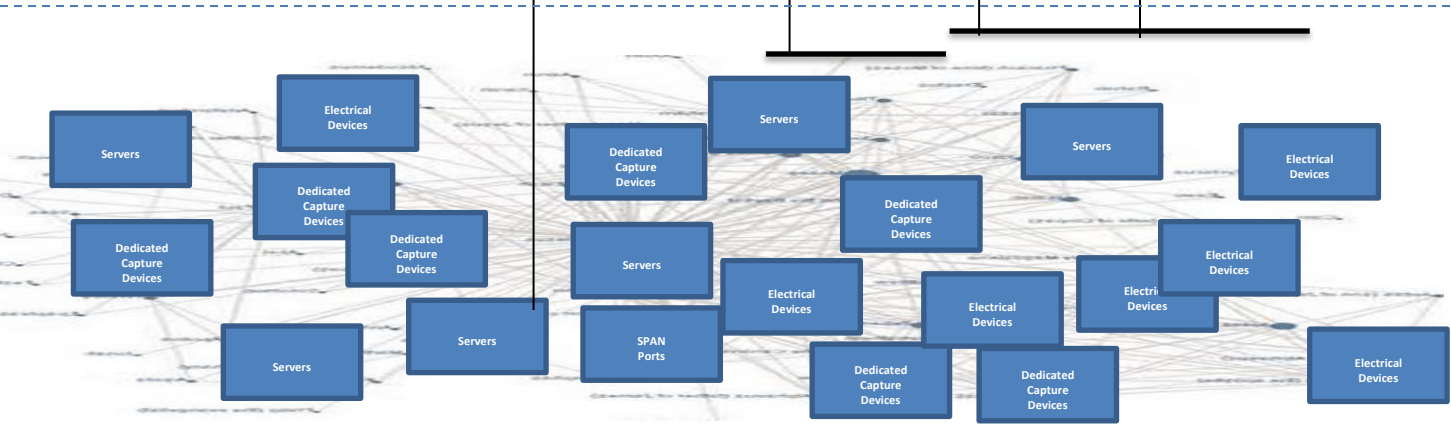
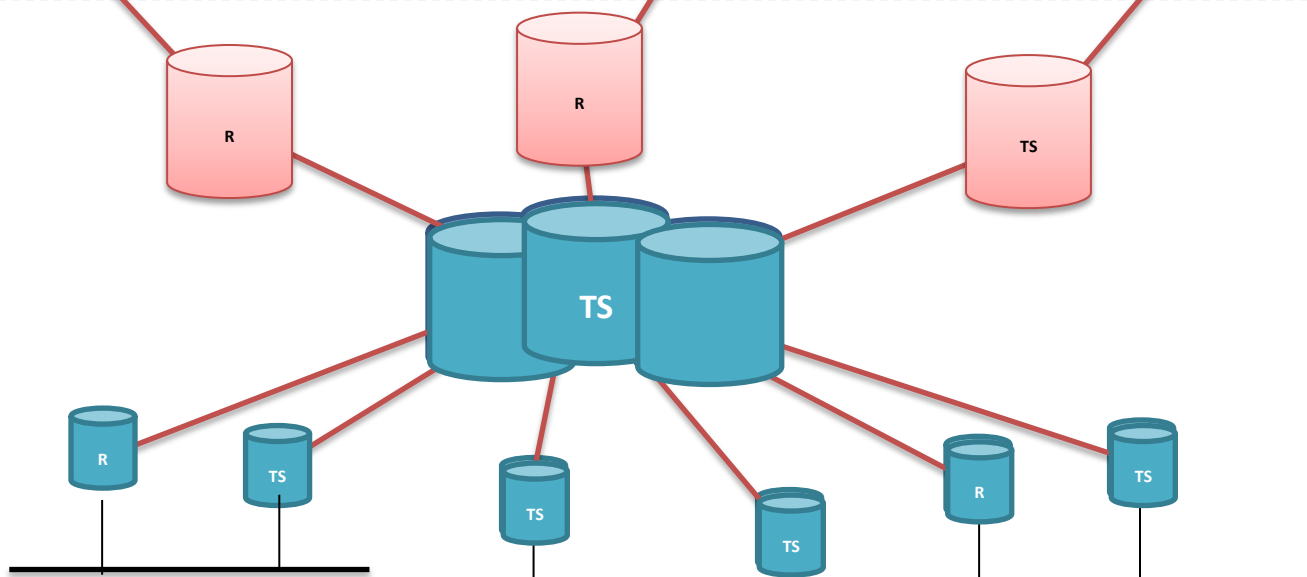
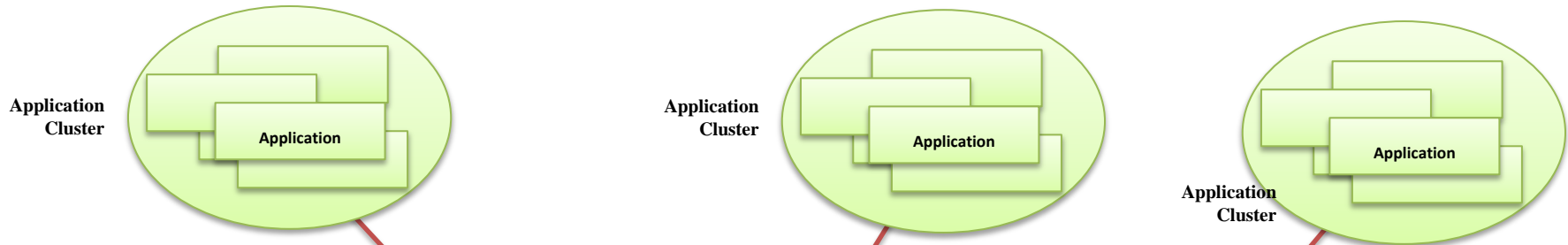
Enterprise Service Bus Architecture for Integration of Complete (full-stack) Applications





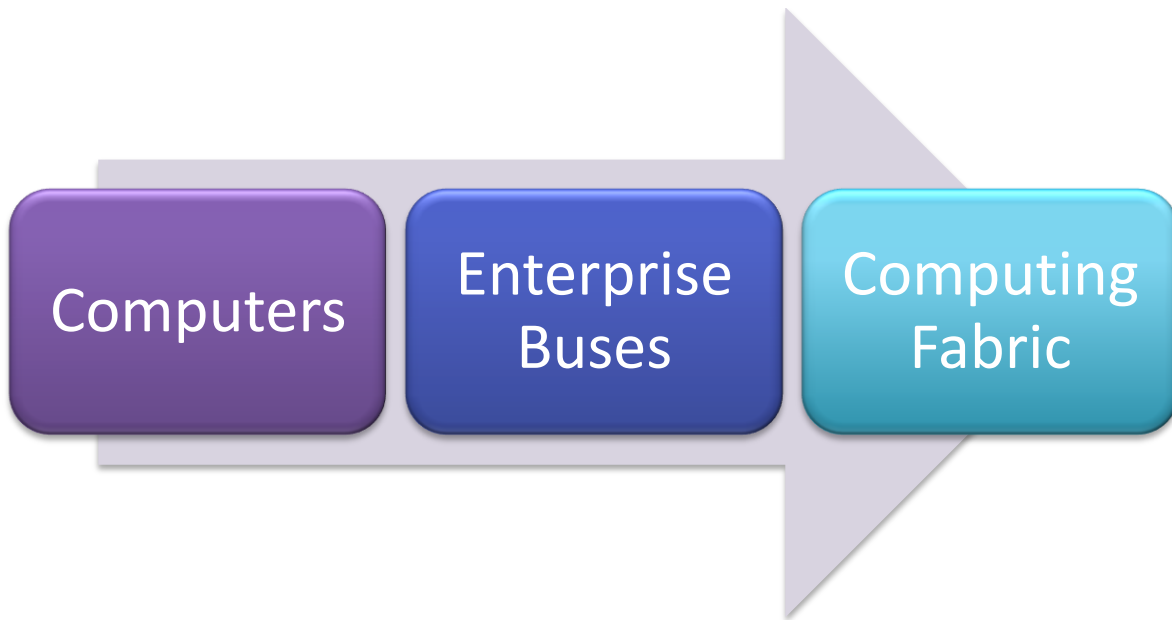
Data level
integration



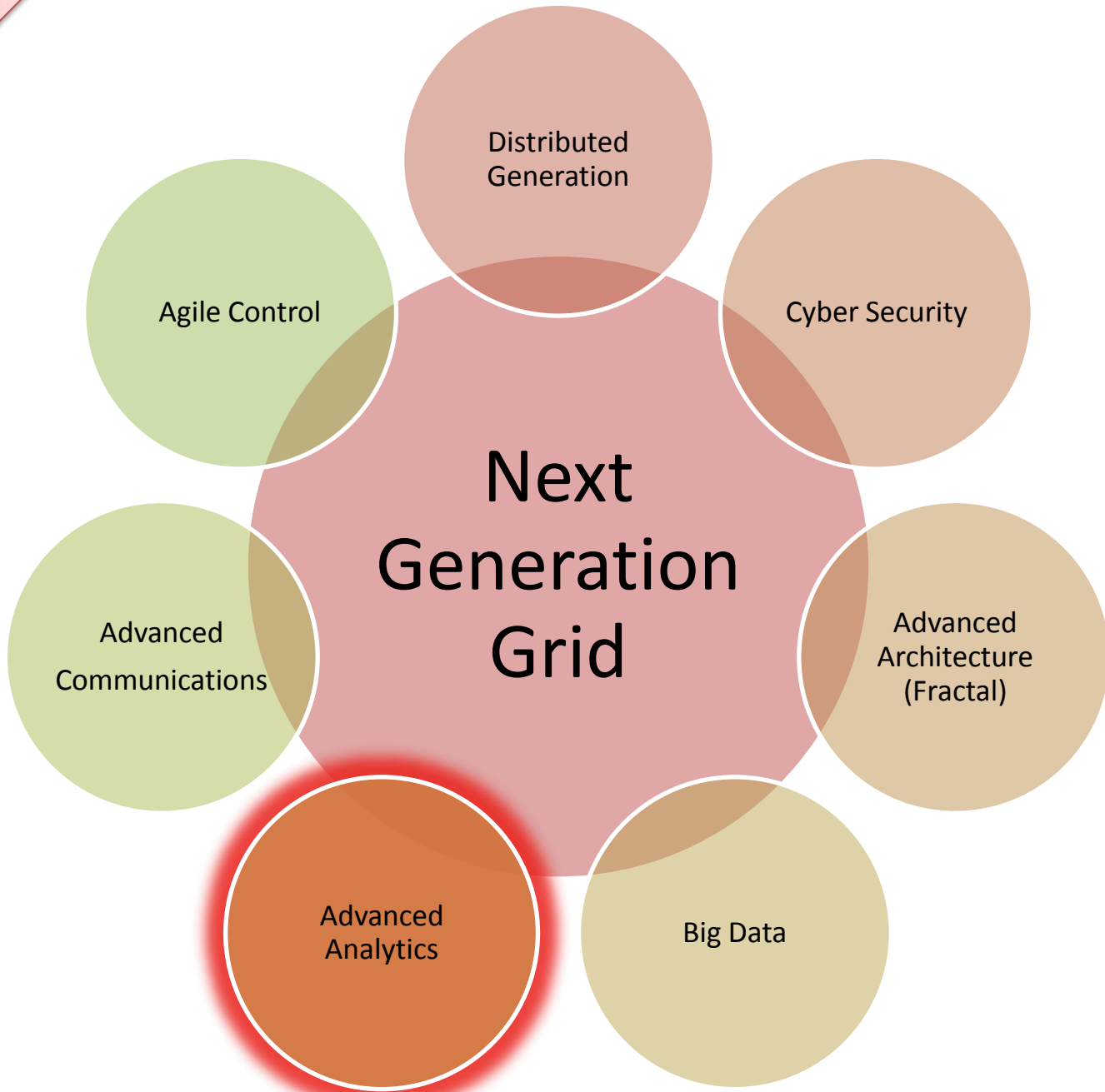


R Relational

TS Time series



FOUNDATIONS



Distributed Generation

Agile Control

Cyber Security

Next Generation Grid

Advanced Communications

Advanced Architecture (Fractal)

Advanced Analytics

Big Data

Analytics are central

1883→ 1990

Control Through Angular Momentum



Transition

2025?→^{ooo}

Analytically Driven Control



ADVANCED STATE ESTIMATION

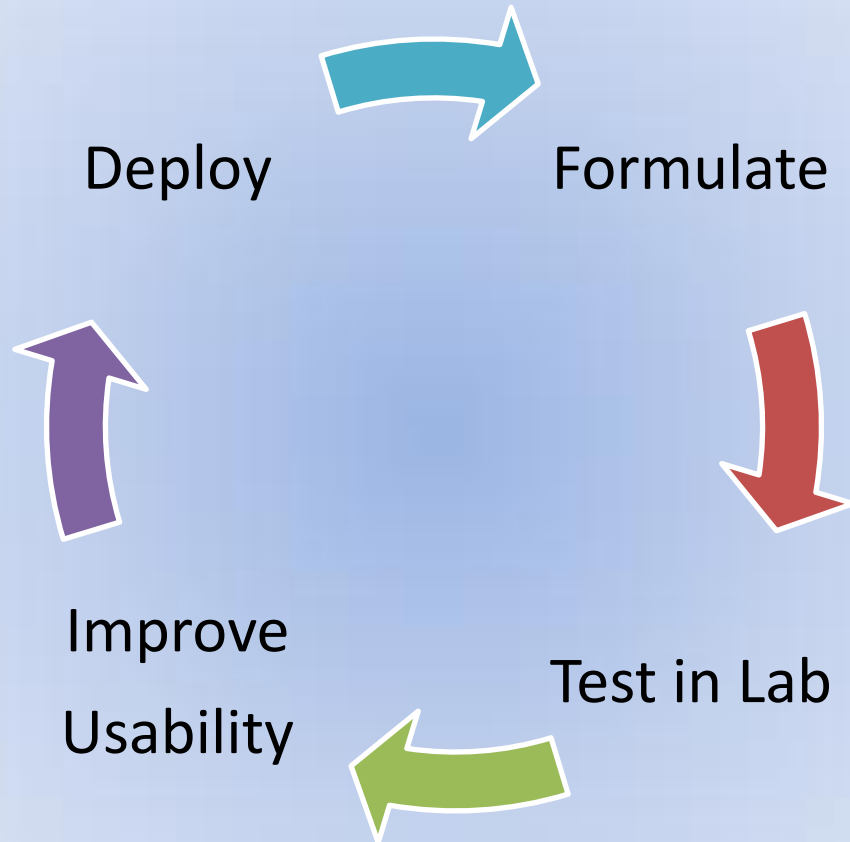
ADVANCED FORECASTING

ADVANCED ANALYTICS

SMART CONTROL



The Analytics Process



Drivers

- **Need – driven by agile grid**
- **Better computers / dollar**
- **Cloud**
- **Modelers are getting smarter**
- **Foundational tools (e.g. GridLab-D)**

Keys to analytics



Shared, consistent data

Open development

Death to silos

Focus first on real problems

Distributed generation

CVR

Big Computing

Cloud

Keys to analytics

Shared, consistent data – **Grid State**

Open development -- **OMF**

Death to silos -- **OMF**

Focus first on real problems

Distributed generation – **SUNDA, using OMF**

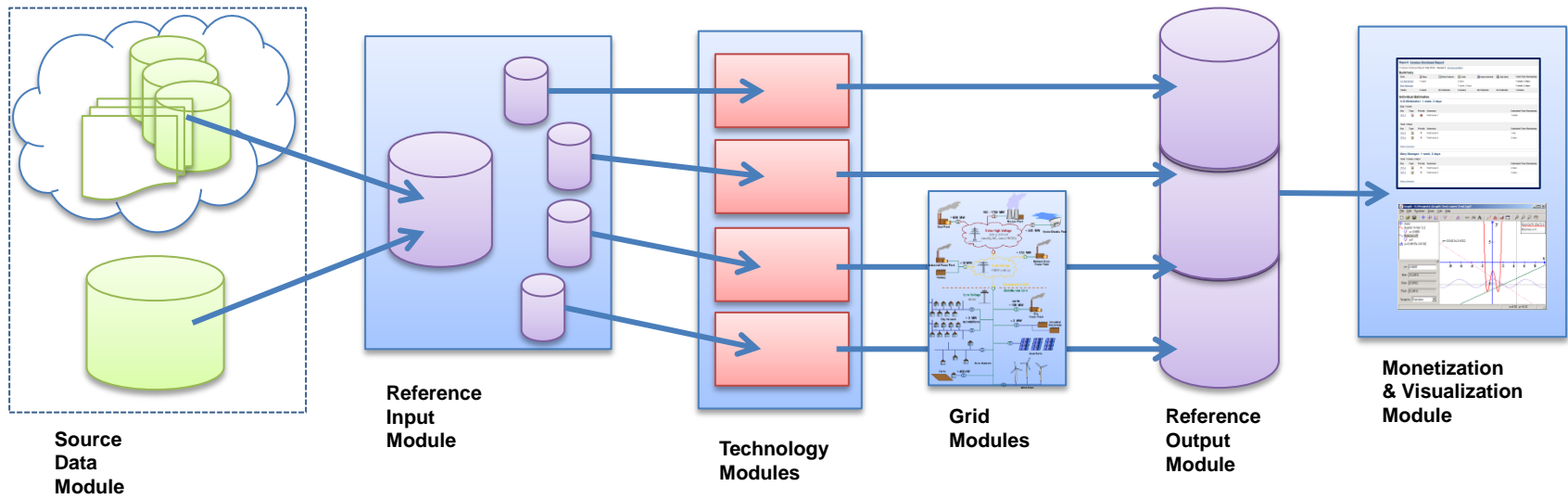
CVR – **Hutchison using OMF**

Resilience – **Sandia, QER using OMF**

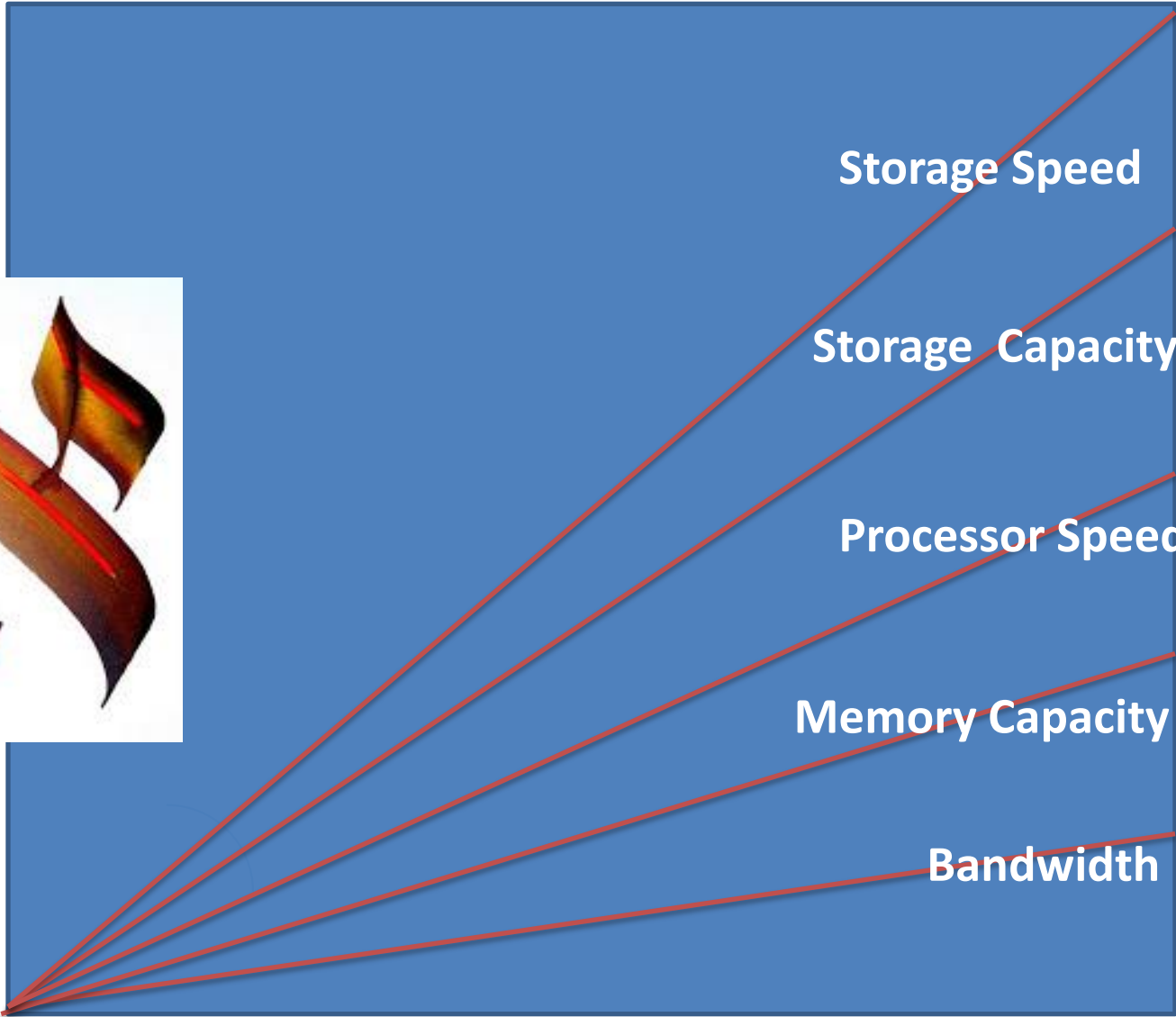
Big Computing – **Intel, GE, Smart America Challenge**

Cloud – ***Intel, GE, Smart American***

Open Modeling Framework







Storage Speed

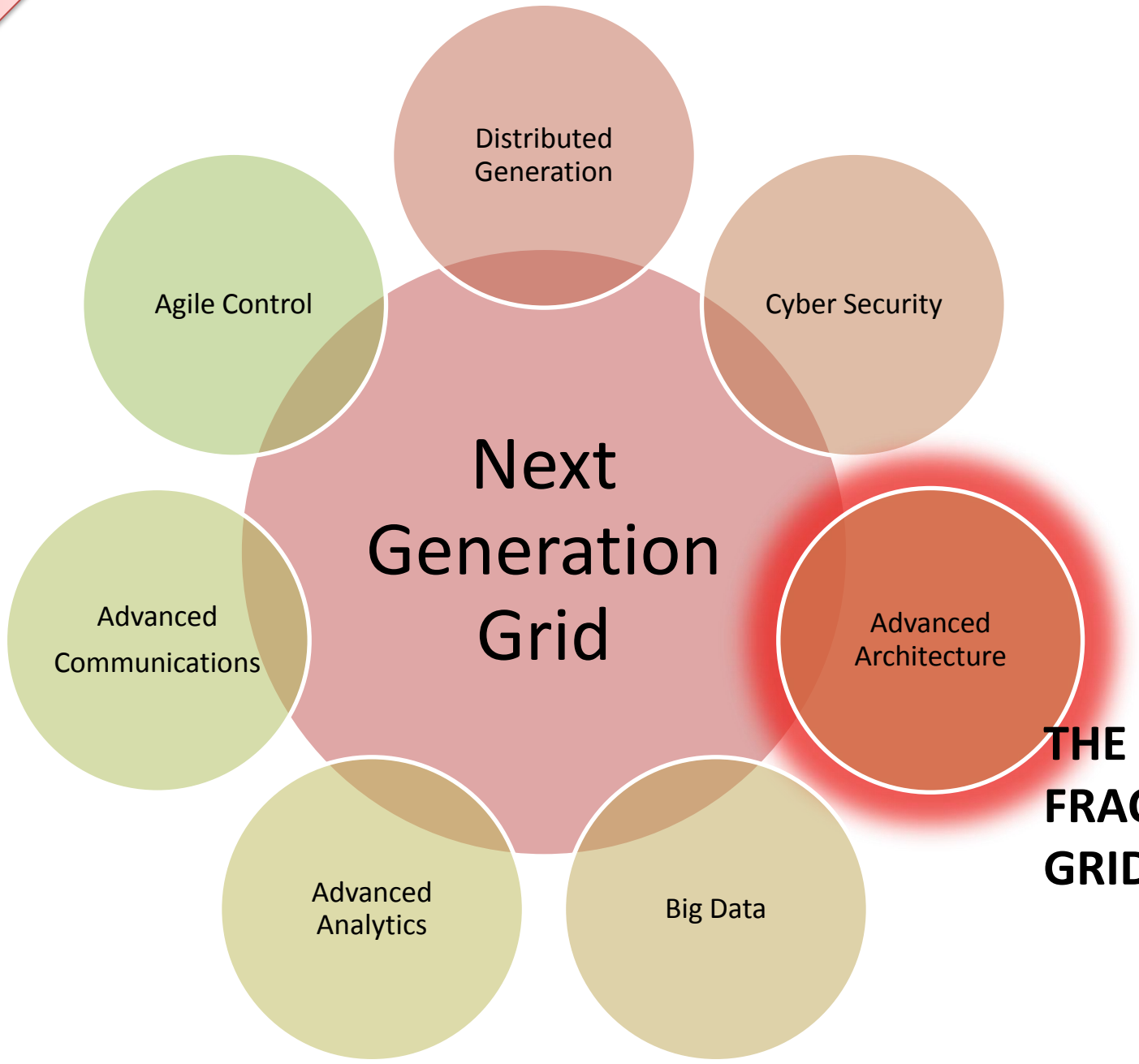
Storage Capacity

Processor Speed

Memory Capacity

Bandwidth

FOUNDATIONS



Next Generation Grid

Cyber Security

Agile Control

Distributed Generation

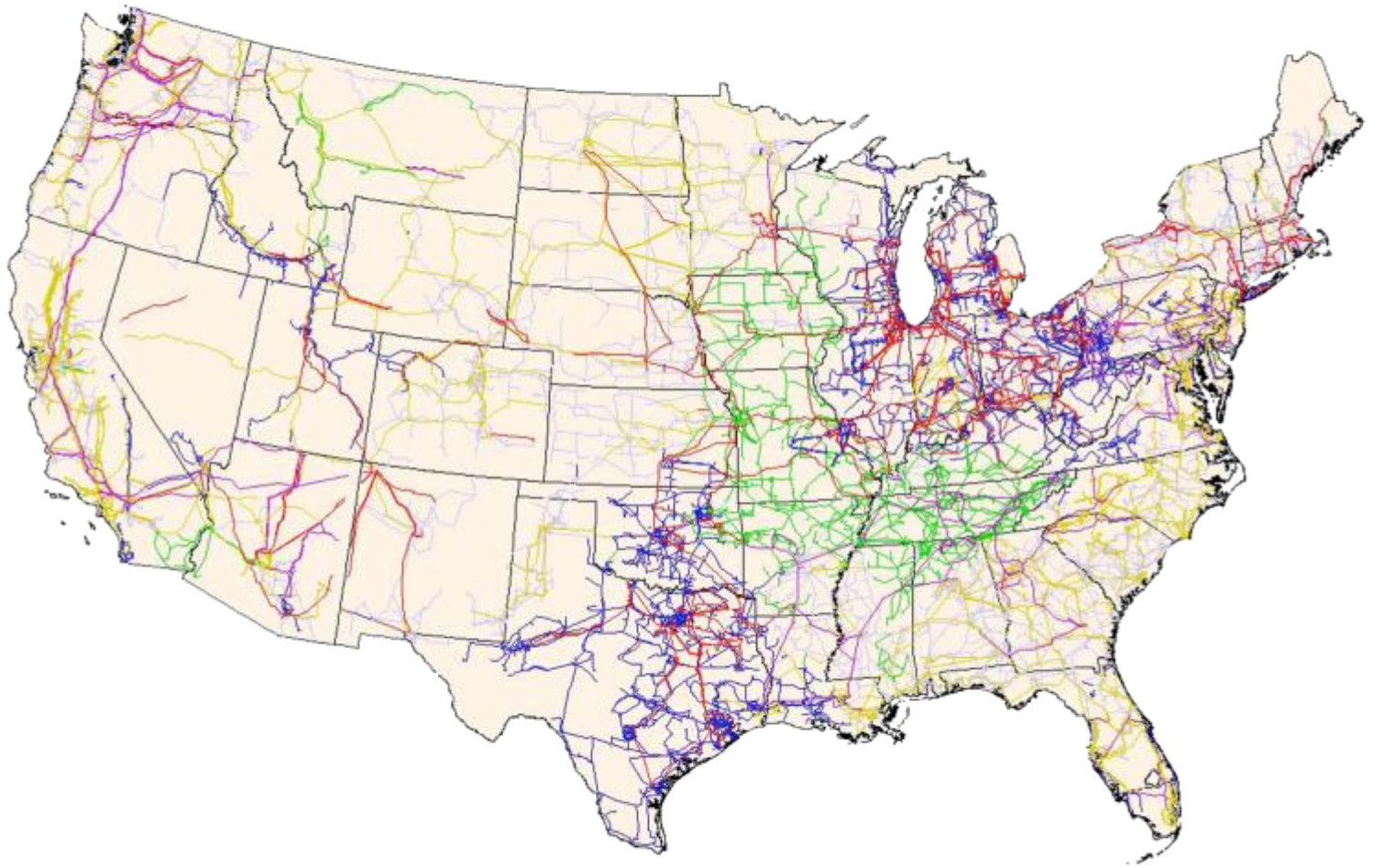
Advanced Communications

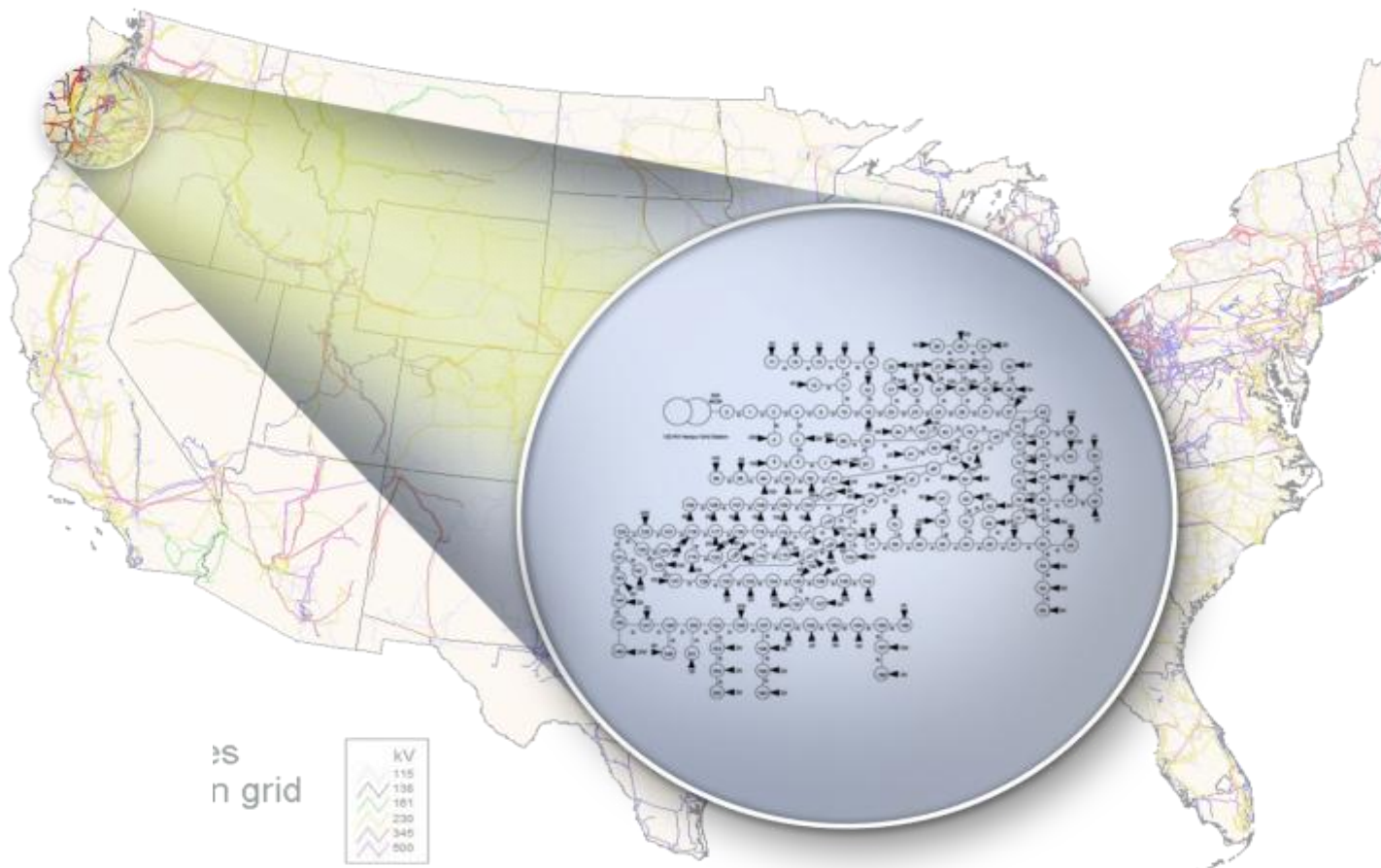
Advanced Architecture

Advanced Analytics

Big Data

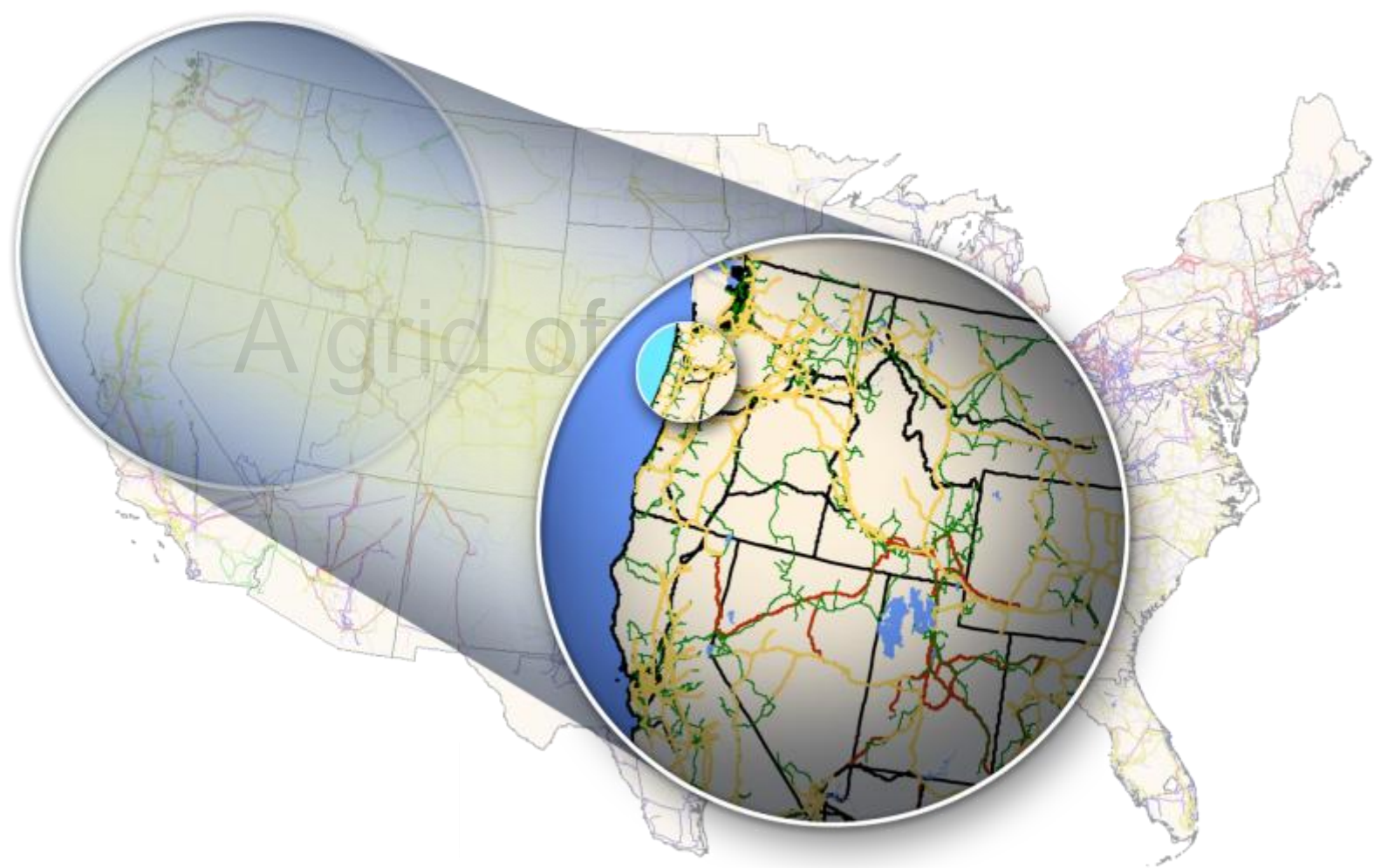
**THE
FRACTAL
GRID**



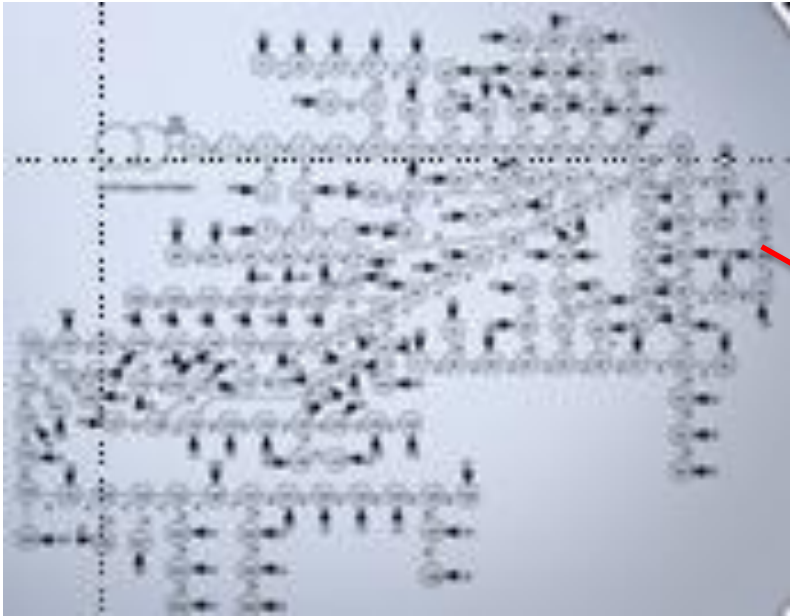


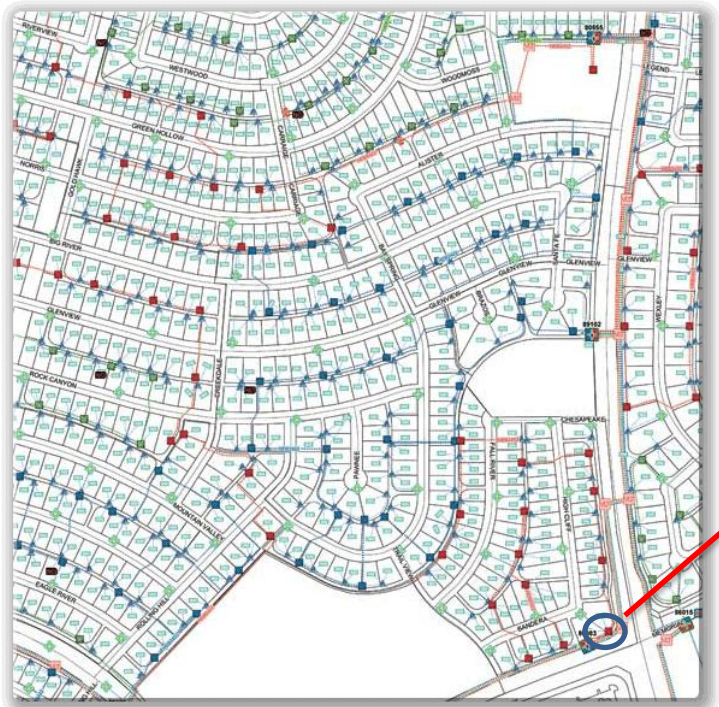
US
n grid





A grid of





A supermarket or a grid?





An office building or a grid?





A home or a grid?



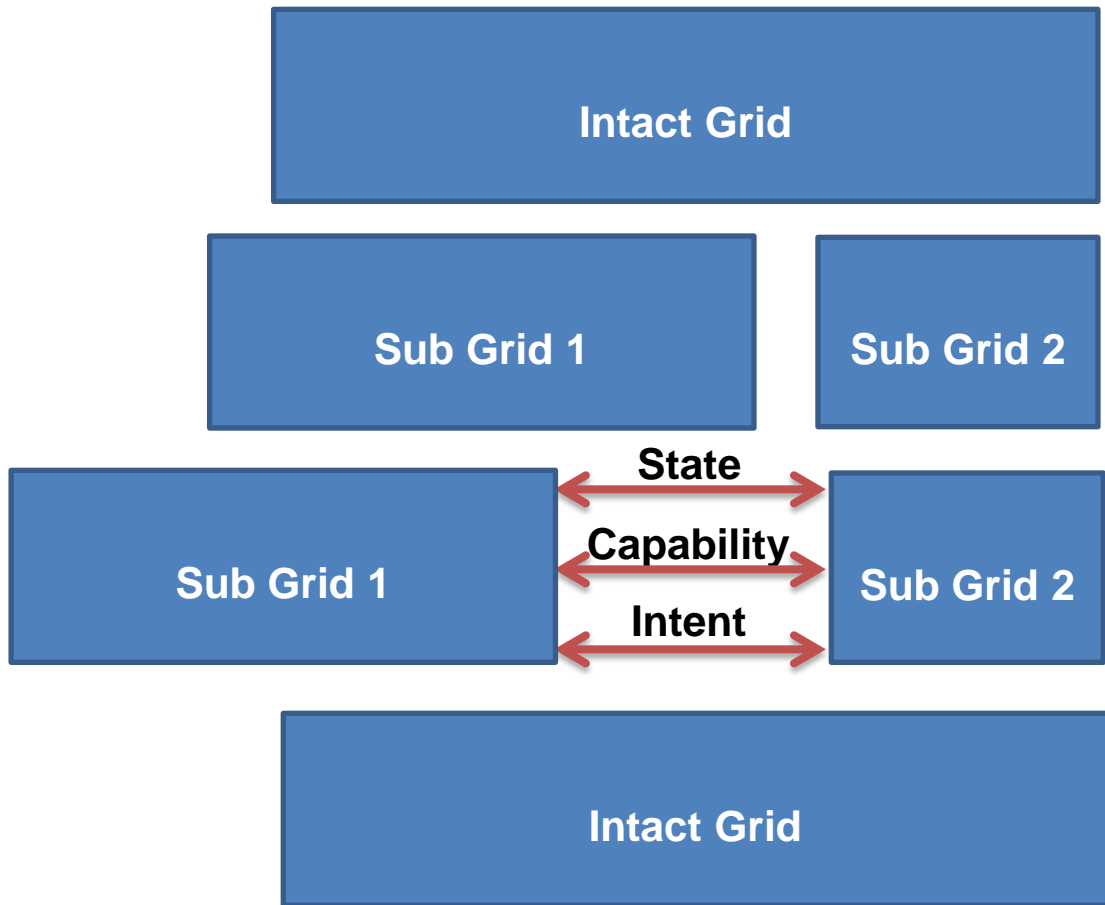
What defines a grid?



Principles of the Fractal Grid

1. All segments of the grid operate with the same information and control model – regardless of scale
2. Every segment of the grid has a decision making capability
3. The means for exchange of peer-to-peer information are clearly defined in standards
4. The rules for when to divide and when to combine are clearly defined

How the resilient grid would work



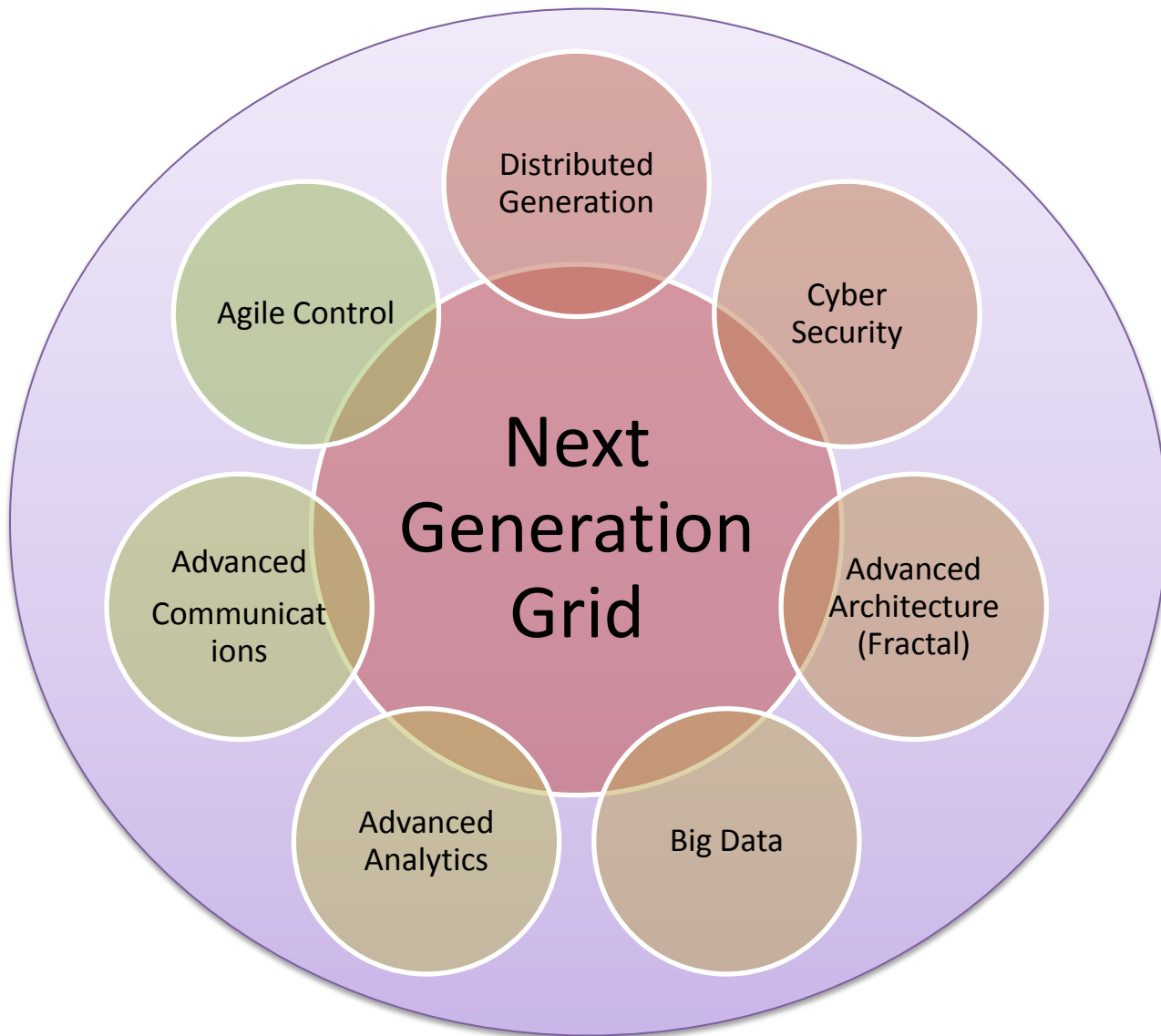
A segment of the grid is operating normally

An event or conditions cause it to bifurcate. Each part operates independently

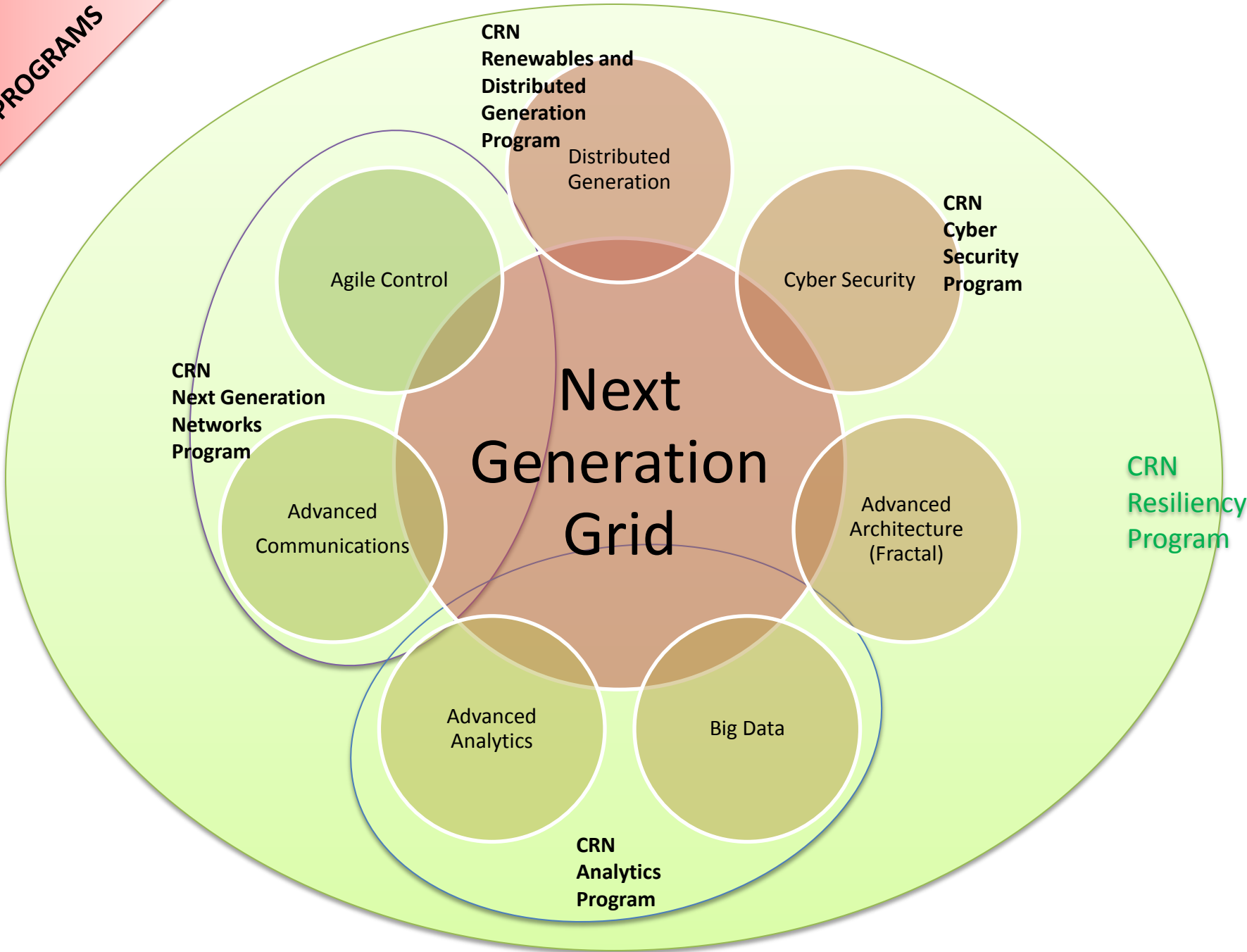
The independent parts exchange information

They “decide” it is time to recombine

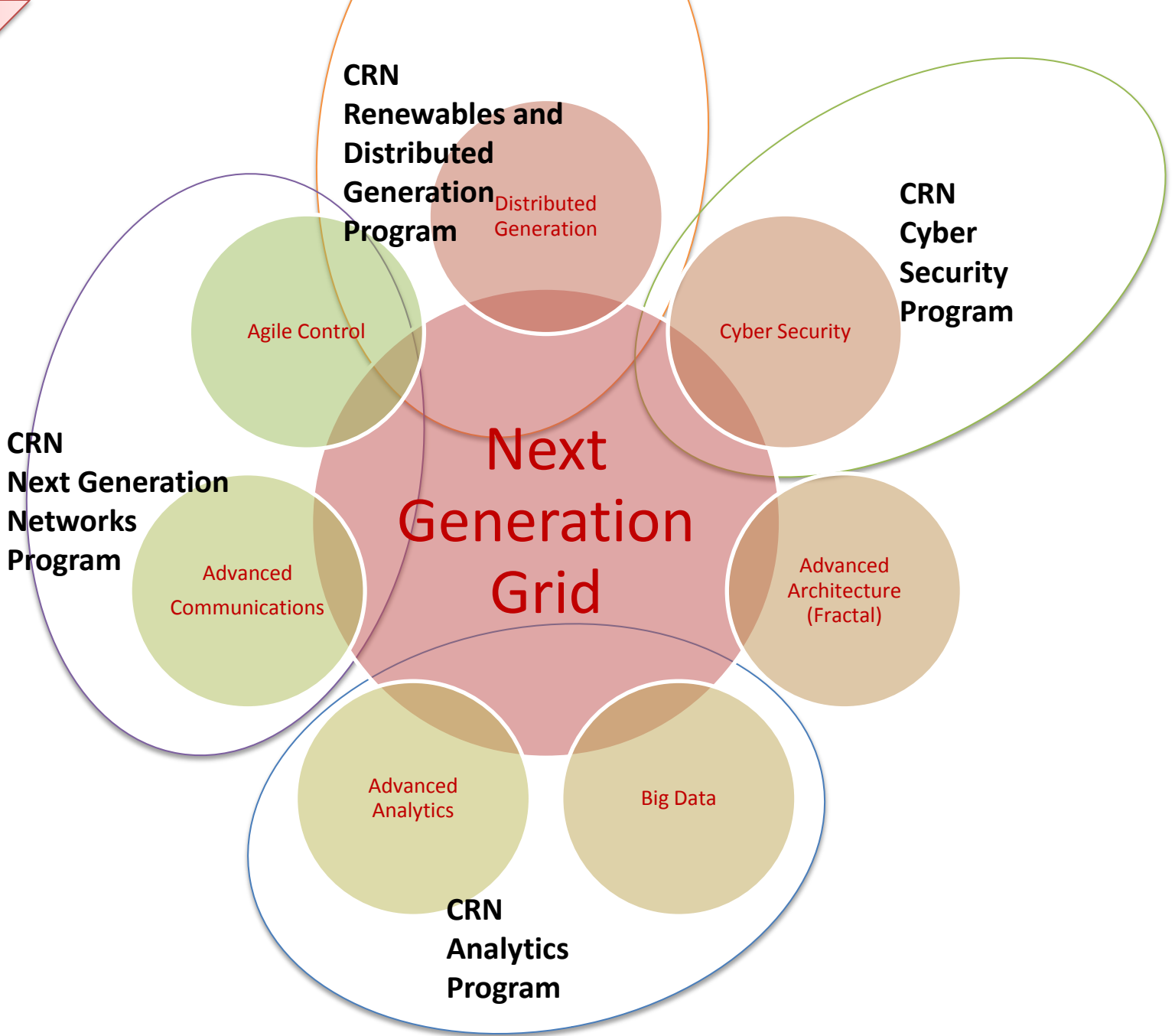
The CRN Program for Resilience



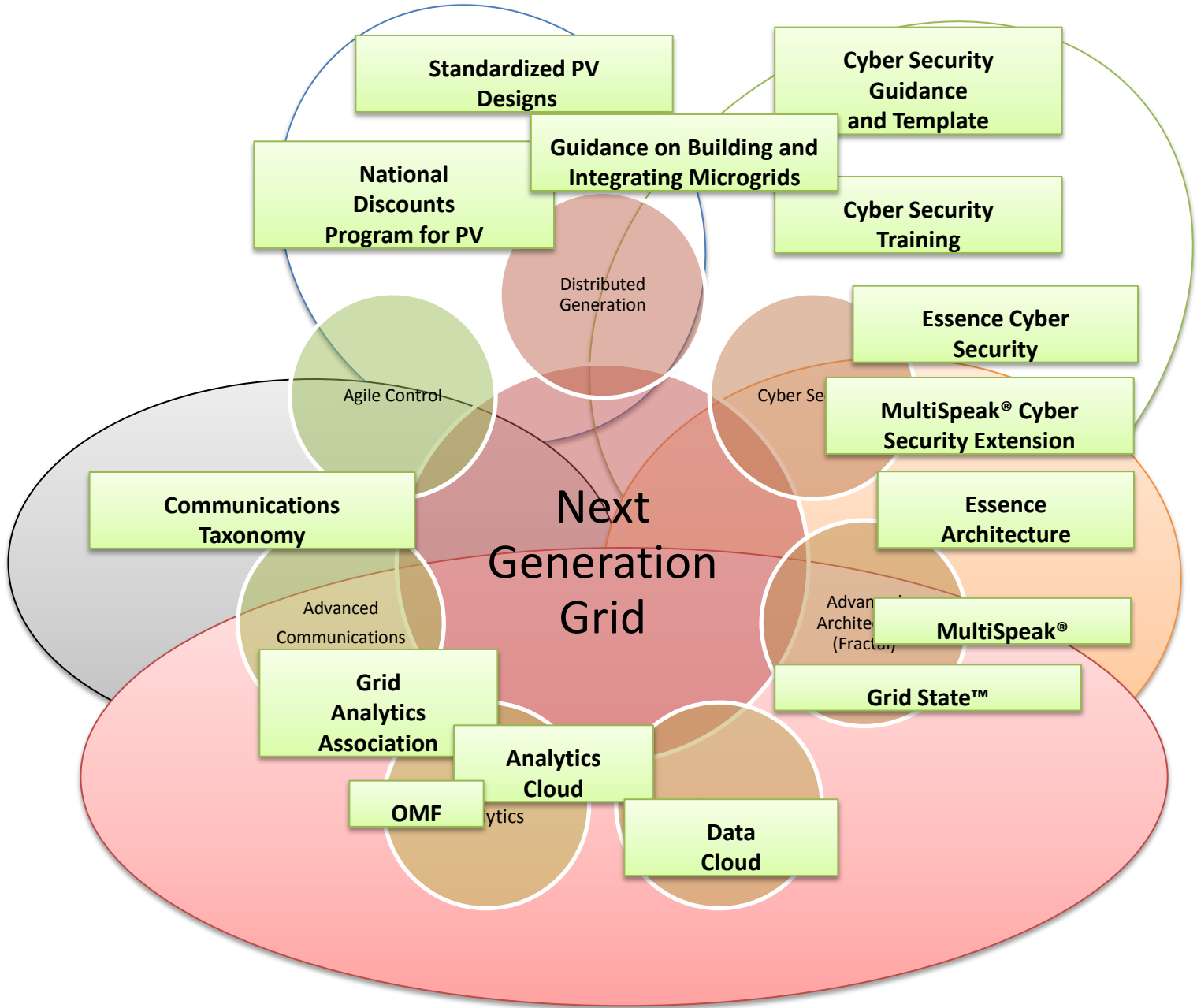
PROGRAMS



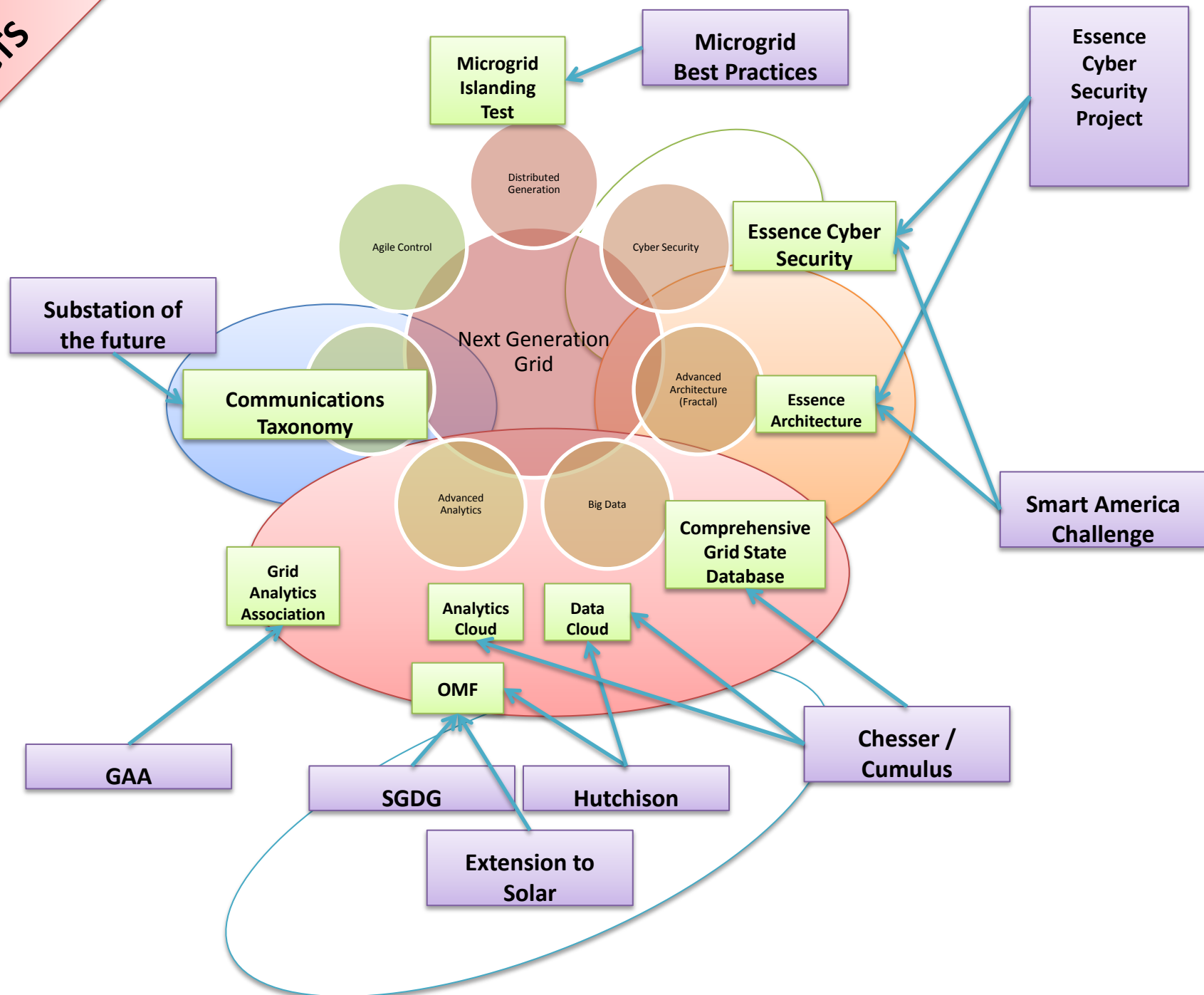
PROGRAMS



PRODUCTS



PROJECTS



PARTNERS

