Current views on future HV infrastructure for Horizon 2030

Mark Waldron

Technical Committee Chairman of CIGRE

WHAT IS CIGRE?

Conseil **I**nternational des **G**rands **R**éseaux **É**lectriques

(International Council On Large Electric Systems)

- Founded in Paris in 1921 as a **worldwide non-profit** association.
- CIGRE addresses issues related to the development, operation and management of electric power systems as well as design, construction, maintenance and disposal of equipment and plant
- CIGRE aims to promote and organize collaboration with experts from all around the world, by sharing knowledge and joining forces to improve the electric power systems of today and tomorrow
- Unbiased, trusted, collaborative, open, breadth and depth of expertise

7729 individual members from 90 countries in 2013

Worldwide Network of Experts

Ministries

Academics

Transmission Companies & System Operators

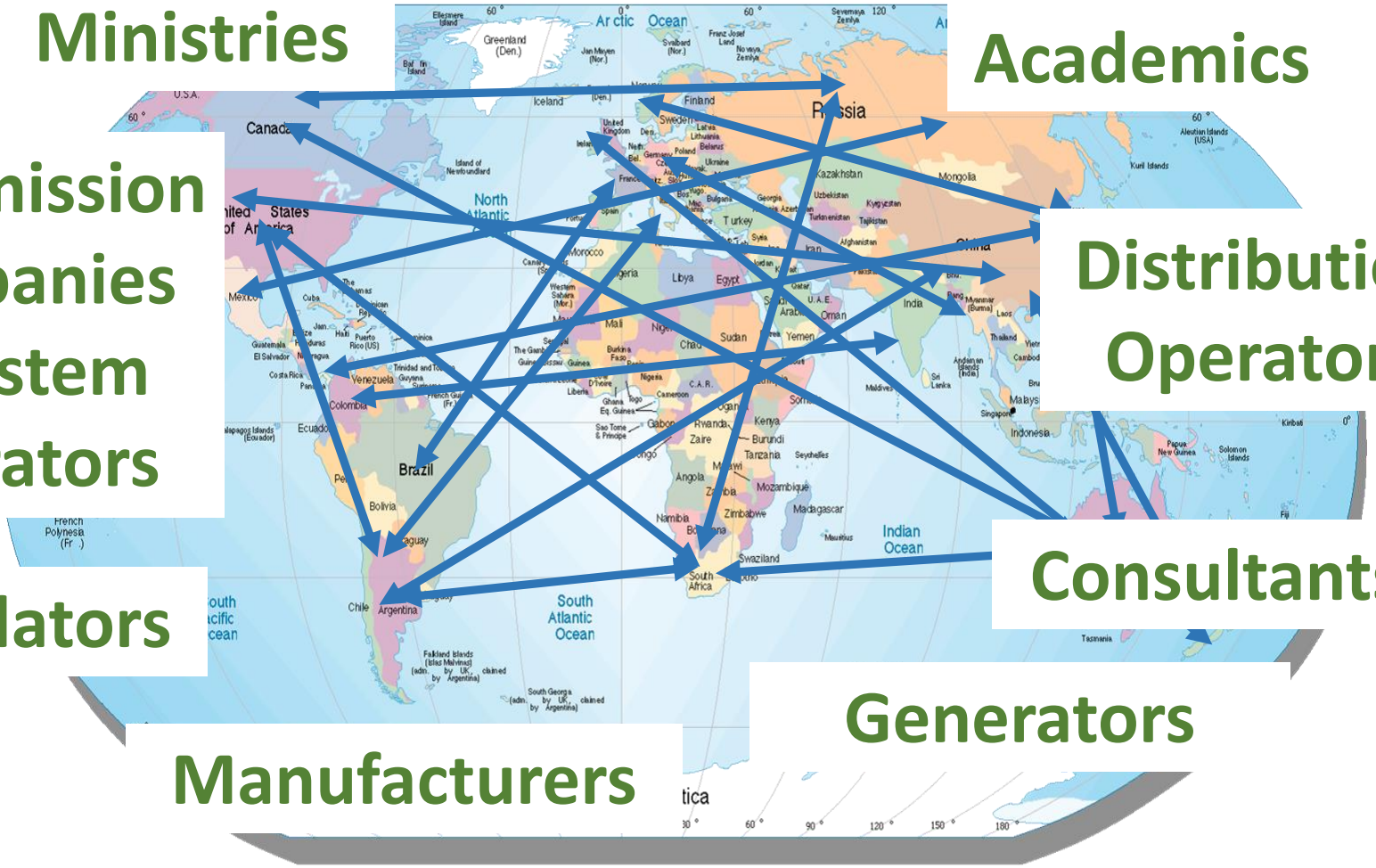
Distribution Operators

Regulators

Consultants

Generators

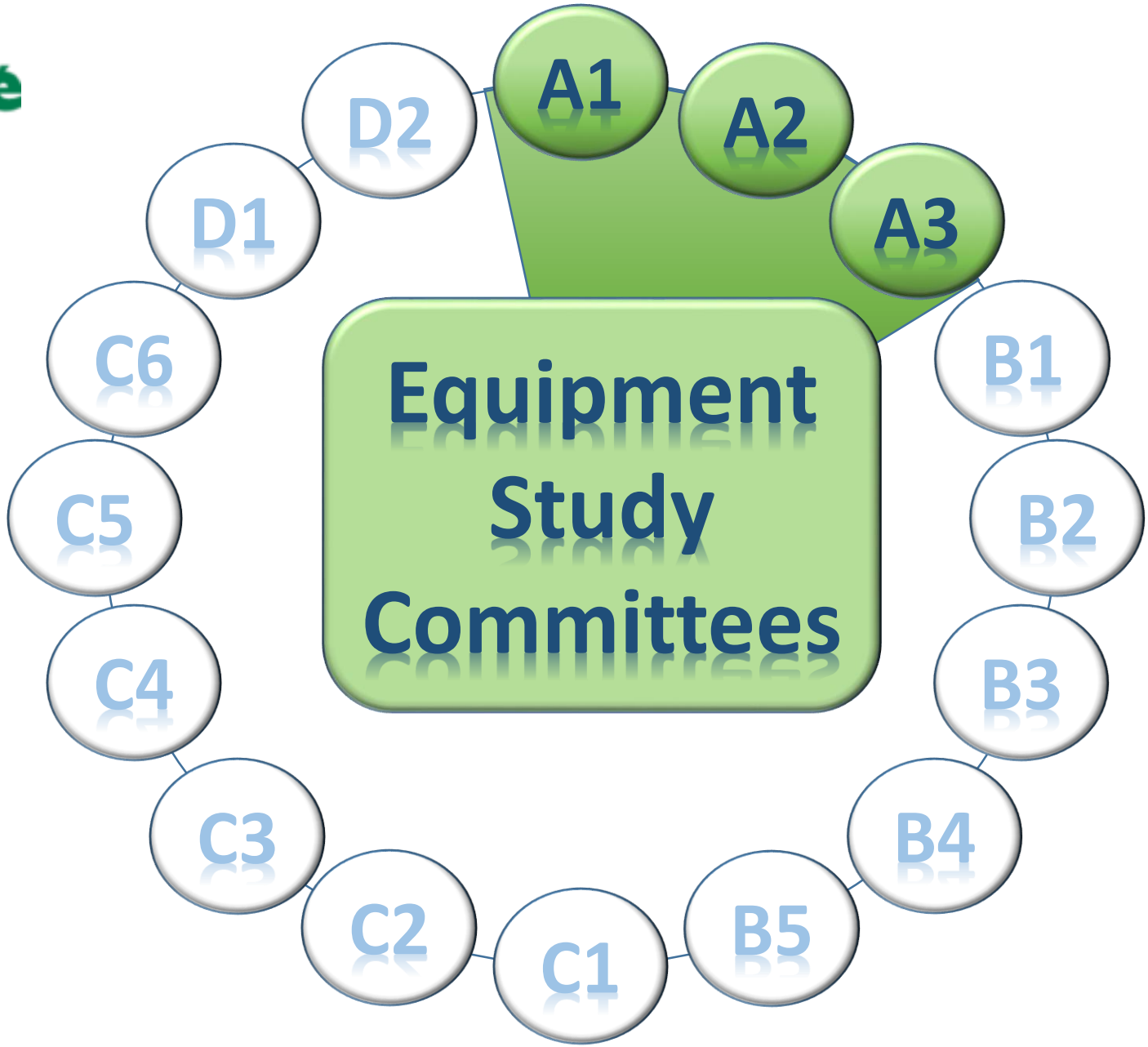
Manufacturers

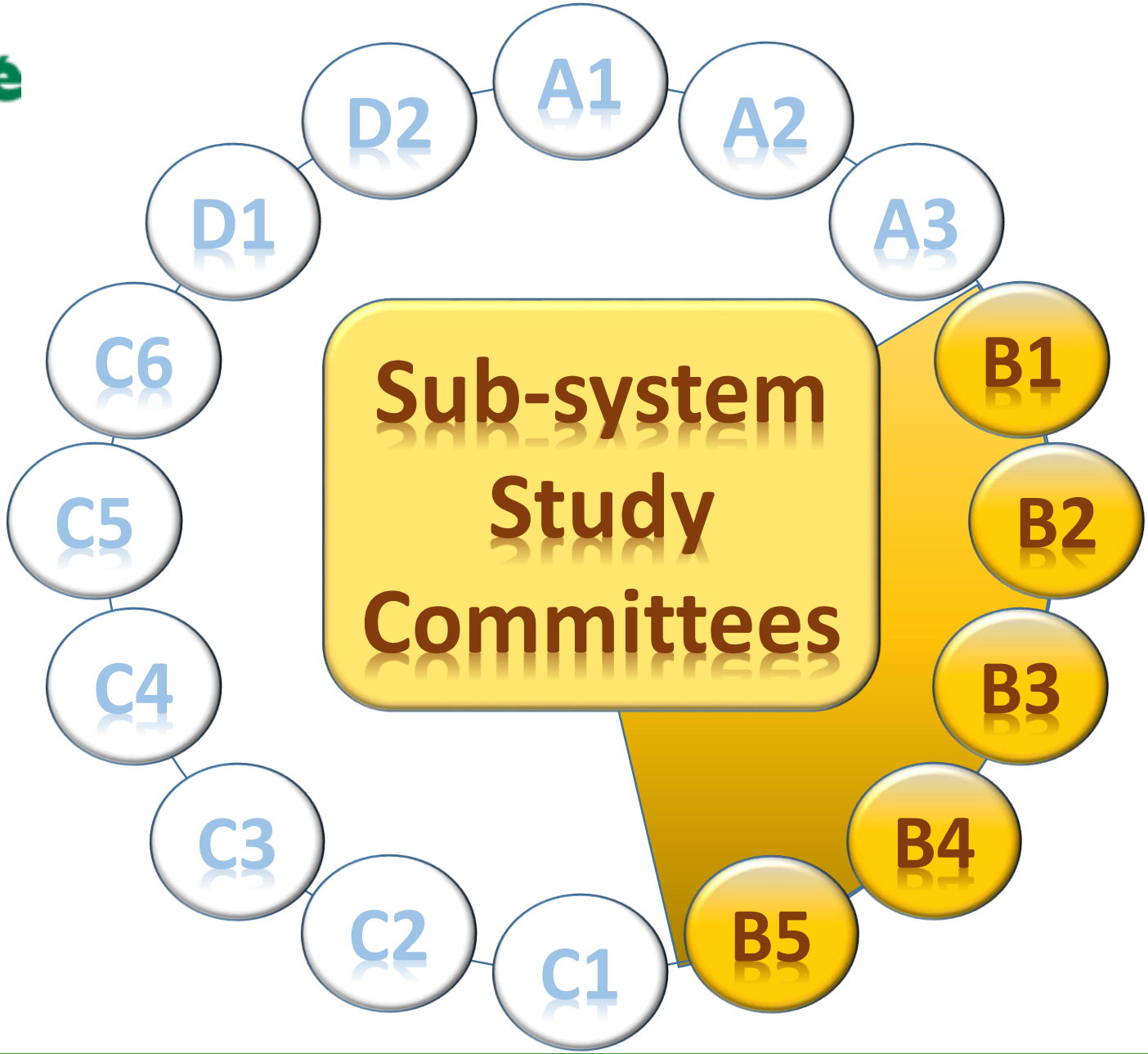


Key Assets of CIGRE

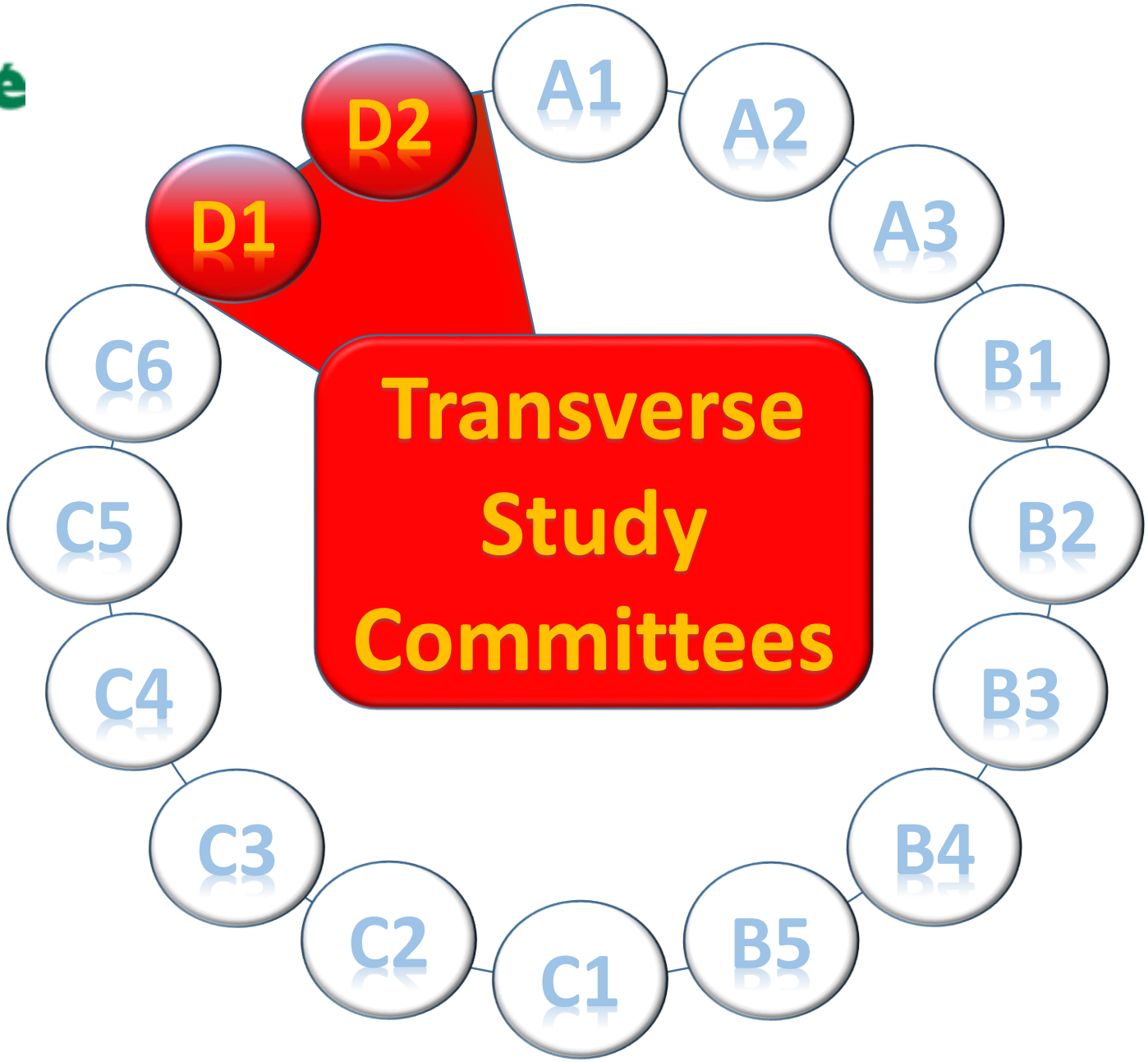
- ❑ Study Committees
- ❑ Working Groups
- ❑ Events
- ❑ Publications
- ❑ Young Members Activities
- ❑ Student Membership


16
Study
Committees
A1
A2
A3
B1
B2
B3
B4
B5
C1
C2
C3
C4
C5
C6
D1
D2


A1
A2
A3
B1
B2
B3
B4
B5
C1
C2
C3
C4
C5
C6
D1
D2
Equipment Study Committees


Sub-system
Study
Committees
A1
A2
A3
B1
B2
B3
B4
B5
C1
C2
C3
C4
C5
C6
D1
D2


System Study Committees
A1
A2
A3
B1
B2
B3
B4
B5
C1
C2
C3
C4
C5
C6
D1
D2

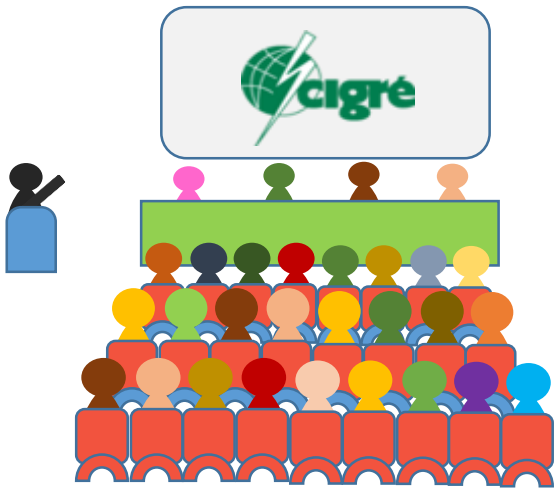

A1
A2
A3
B1
B2
B3
B4
B5
C1
C2
C3
C4
C5
C6
D1
D2
Transverse Study Committees

WORKING GROUPS

Technical Brochures

230 Working Groups produce between 40 and 50 Technical Brochures per year

CIGRE EVENTS



- **Paris Sessions**

…
2009
2010
2011
2012
2013
2014

- **Symposia**

Calgary (CA)
Guilin (CN)
Bologna (IT)
Recife (BR)
Lisbon (PT)
Auckland (NZ)

…
2009
2010
2011
2012
2013
2014

- **Colloquia & Regional events**

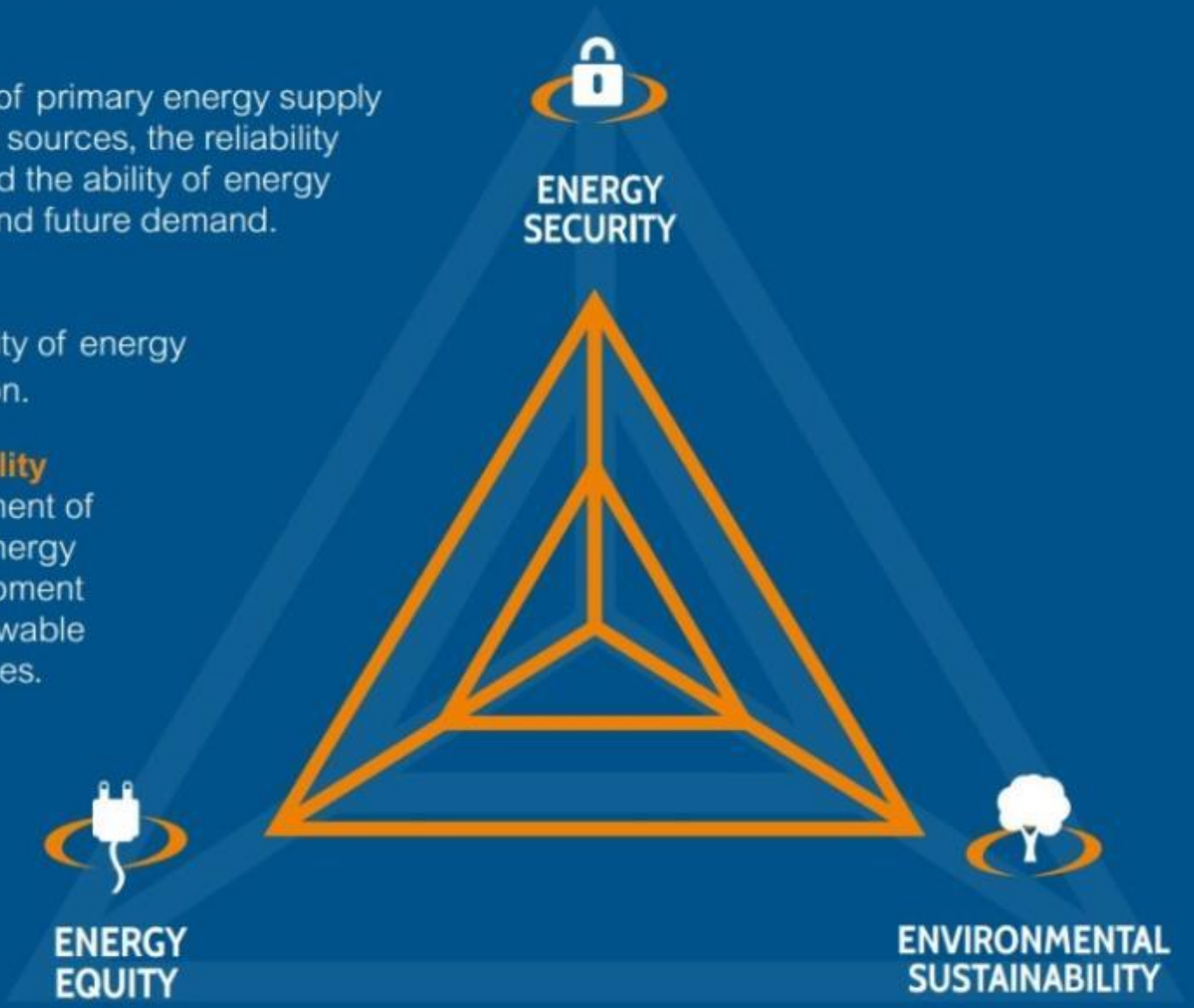
Transition and the Energy Trilemma

Balancing the 'Energy Trilemma'

Energy Security
The effective management of primary energy supply from domestic and external sources, the reliability of energy infrastructure, and the ability of energy providers to meet current and future demand.

Energy Equity
Accessibility and affordability of energy supply across the population.

Environmental Sustainability
Encompasses the achievement of supply and demand side energy efficiencies and the development of energy supply from renewable and other low carbon sources.



Growth and Transition

Demographic dynamics

- **Population growth**
  7.5b, in 2020
- **Megacities** (>10m people)
  27 megacities by 2025

Source: JNO

Rising energy consumption

Abundant but unevenly distributed resources

- **Geopolitics**
  70% of global oil and gas reserves are located in just a few countries
- **Oil price fluctuations**

Growing demand for energy efficiency

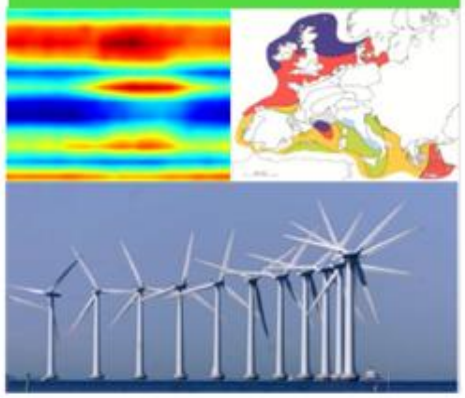
Climate change

- **Climate goals**
  Political programes aimed at long term reduction in CO_2 emissions

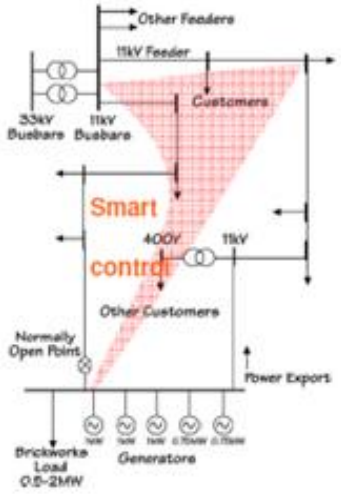
Growing demand for "clean" electricity

Energy Challenge…

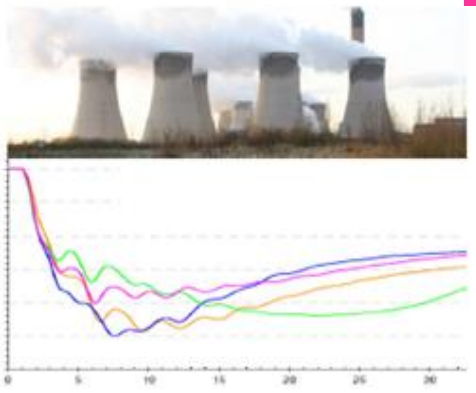
Variable Generation



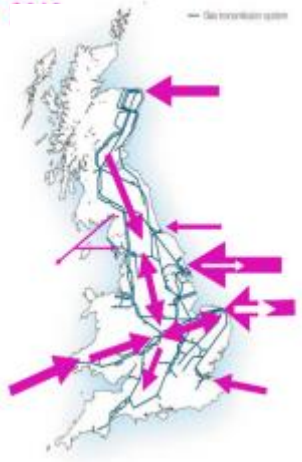
Active Distribution



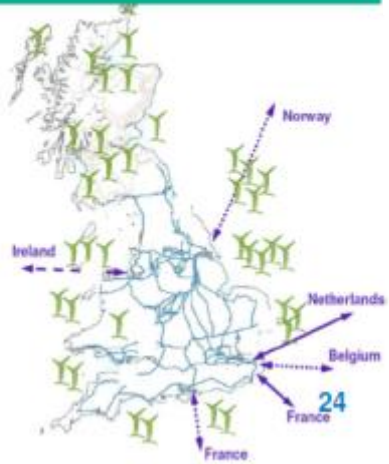
Large Generation



Network Flexibility

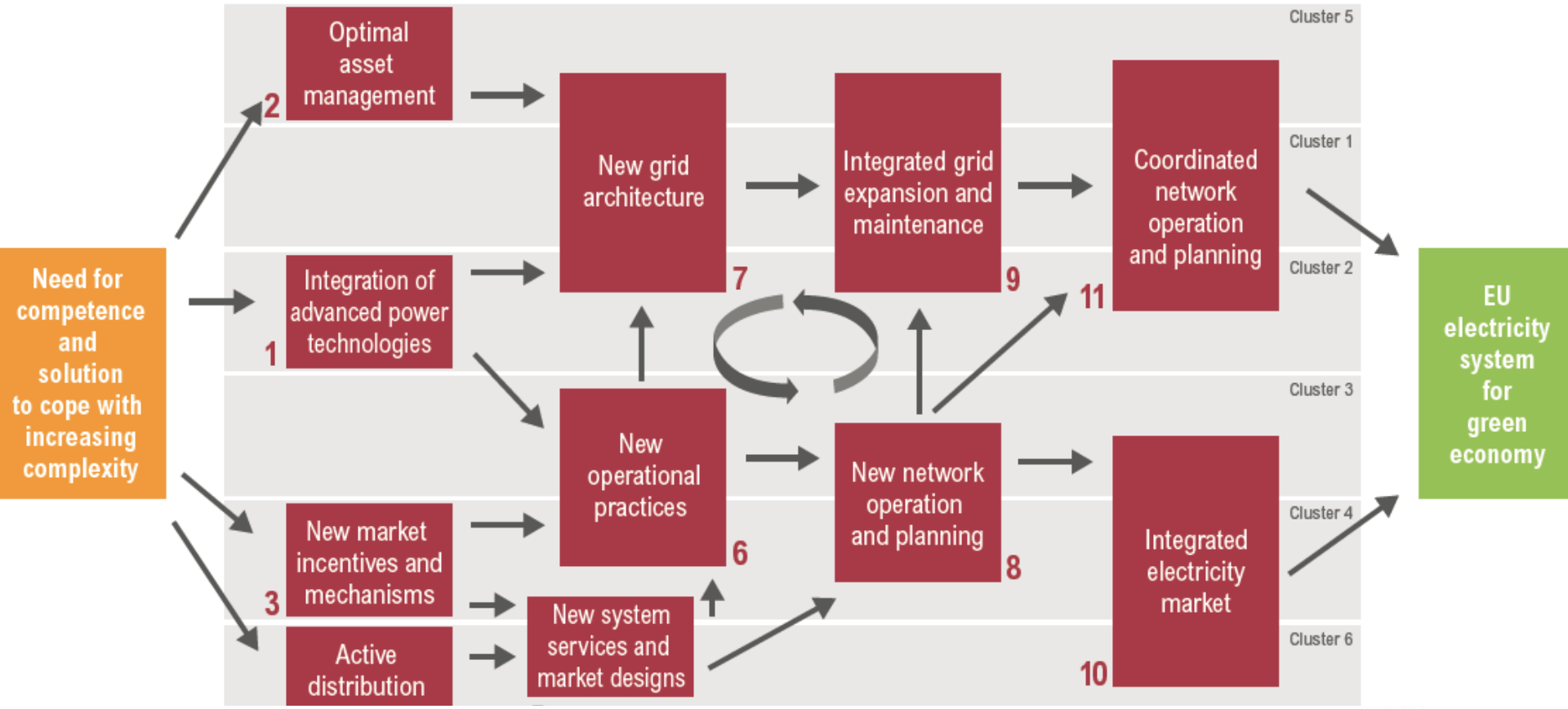


Greater Interconnection



Active Demand

ENTSO-E



C6: Joint TSO/DSO R&D activities

C5: Asset management

C4: Market designs

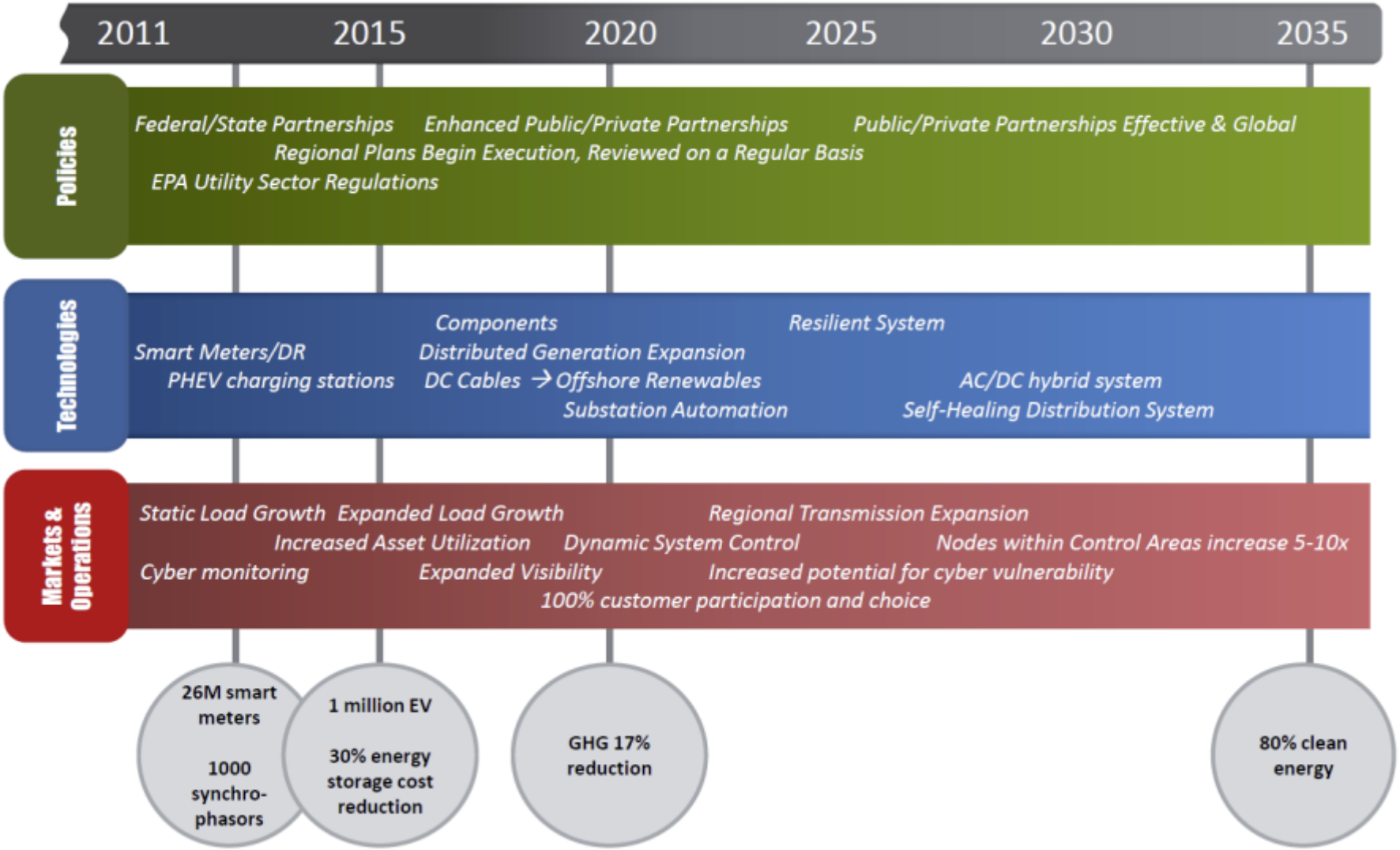
C3: Network operation

C2: Power technologies

C1: Grid architecture

Towards a sustainable power system

U.S. View


2011
2015
2020
2025
2030
2035
Policies
Federal/State Partnerships
Enhanced Public/Private Partnerships
Public/Private Partnerships Effective & Global
Regional Plans Begin Execution, Reviewed on a Regular Basis
EPA Utility Sector Regulations
Technologies
Components
Resilient System
Smart Meters/DR
Distributed Generation Expansion
PHEV charging stations
DC Cables → Offshore Renewables
AC/DC hybrid system
Substation Automation
Self-Healing Distribution System
Markets & Operations
Static Load Growth
Expanded Load Growth
Regional Transmission Expansion
Increased Asset Utilization
Dynamic System Control
Nodes within Control Areas increase 5-10x
Cyber monitoring
Expanded Visibility
Increased potential for cyber vulnerability
100% customer participation and choice
26M smart meters
1000 synchro-phasors
1 million EV
30% energy storage cost reduction
GHG 17% reduction
80% clean energy

Power system of the future

Active Distribution Networks

Massive Exchange of Information

Integration of HVDC / Power Electronics

Massive Installation of Storage

New Systems Operations / Controls

New Concepts for Protection

New Concepts in Planning

New Tools for Technical Performance

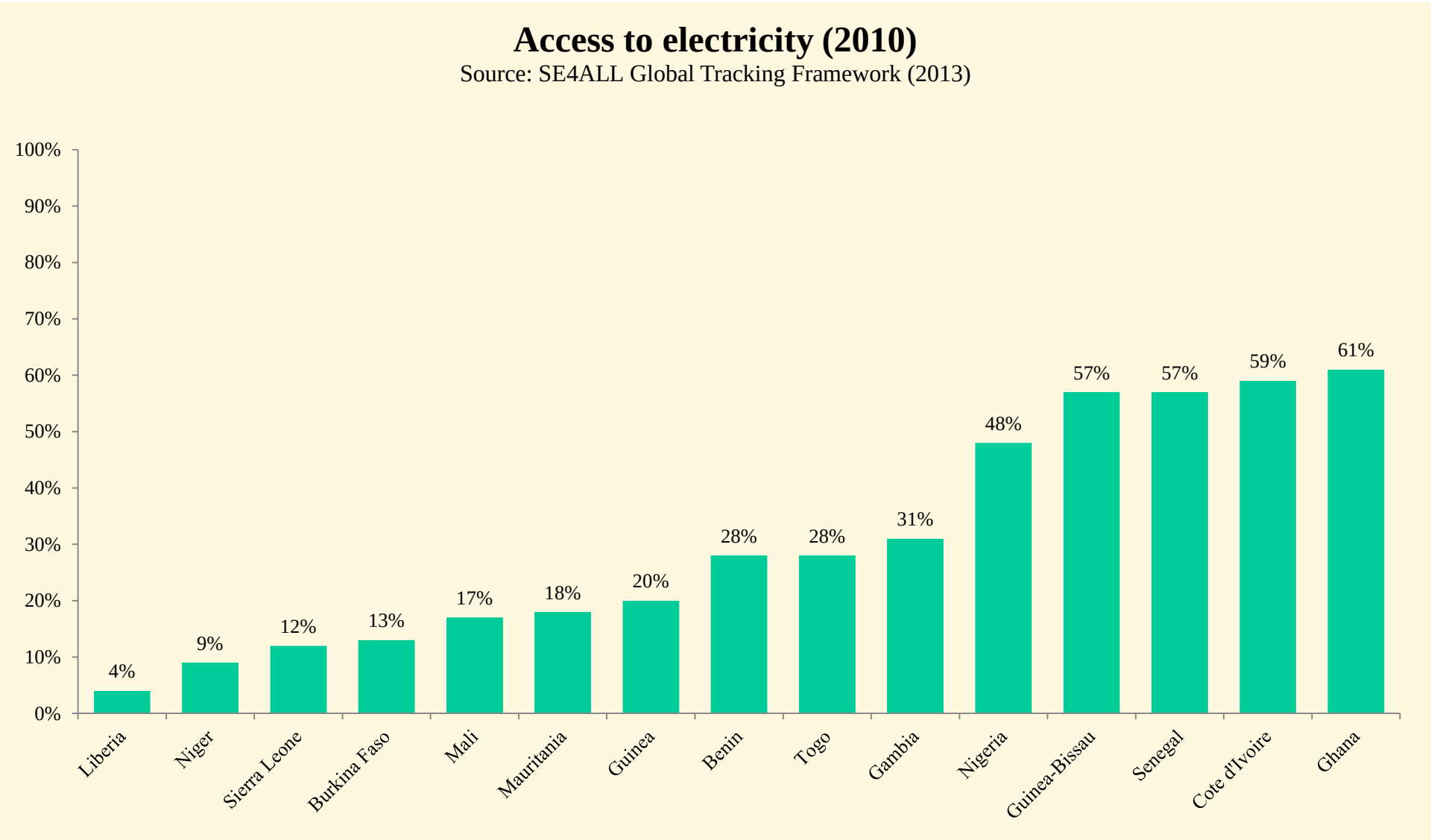
Increase of Underground Infrastructure

Need for Stakeholder Awareness

10 Technical Issues

Region	Population without electricity millions	Electrification rate %	Urban rate %	Rural rate %
Developing countries	**1,257**	**76.5**	**90.6**	**65.1**
Africa	600	43	65	28
North Africa	*1*	*99*	*100*	*99*
Sub-Saharan Africa	*599*	*32*	*55*	*18*
Developing Asia	615	83	95	75
India	*306*	*75*	*94*	*67*
Rest of developing Asia	*309*	*87*	*95*	*80*
Latin America	24	95	99	81
Middle East	19	91	99	76
Transition economies & OECD	**1**	**99.9**	**100.0**	**99.7**
World	**1,258**	**81.9**	**93.7**	**69.0**

A long way to go



Key Themes

- Uncertainty
- Renewable Integration
- Interconnection & Bulk Transportation
- Storage
- “SMART” T&D
- Sustainability & Environment
- Sophisticated Asset Management
- Standardisation; view to 2030

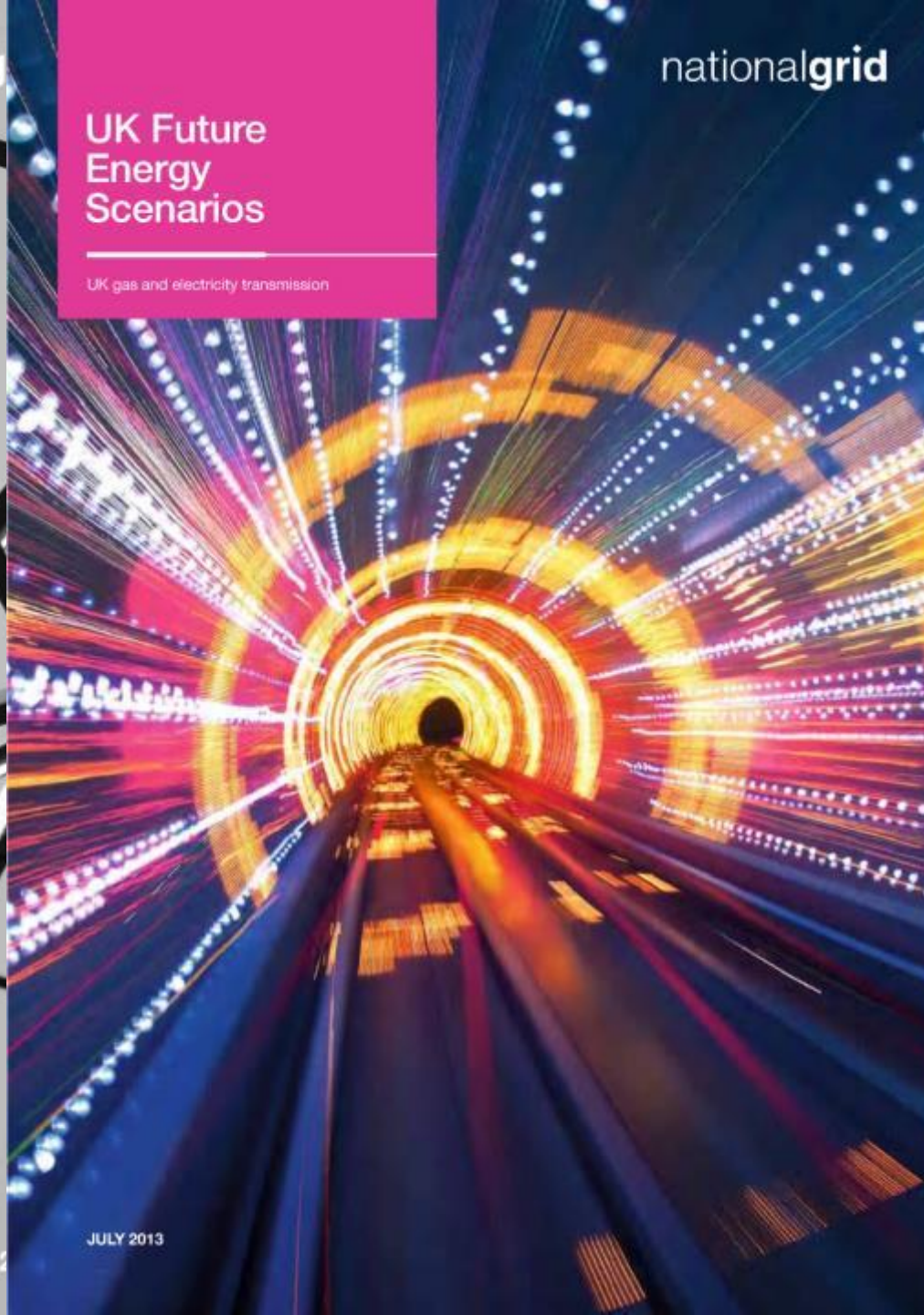
Uncertainty

nationalg

Electricity Ten Year Statement

UK electricity transmission

NOVEMBER 2



nationalgrid

UK Future Energy Scenarios

UK gas and electricity transmission

JULY 2013

UK scenarios

- **Consumer Power** is a world of relative wealth, fast paced research and development and spending. Innovation is focused on meeting the needs of consumers, who focus on improving their quality of life.
- **Gone Green** is a world where green ambition is not restrained by financial limitations. New technologies are introduced and embraced by society, enabling all carbon and renewable targets to be met on time.
- **Slow Progression** is a world where slower economic growth restricts market conditions. Money that is available is spent focusing on low cost long-term solutions to achieve decarbonisation, albeit later than the target dates.
- **No Progression** is a world focused on achieving security of supply at the lowest possible cost. With low economic growth, traditional sources of gas and electricity dominate, and little innovation affecting how we use energy.

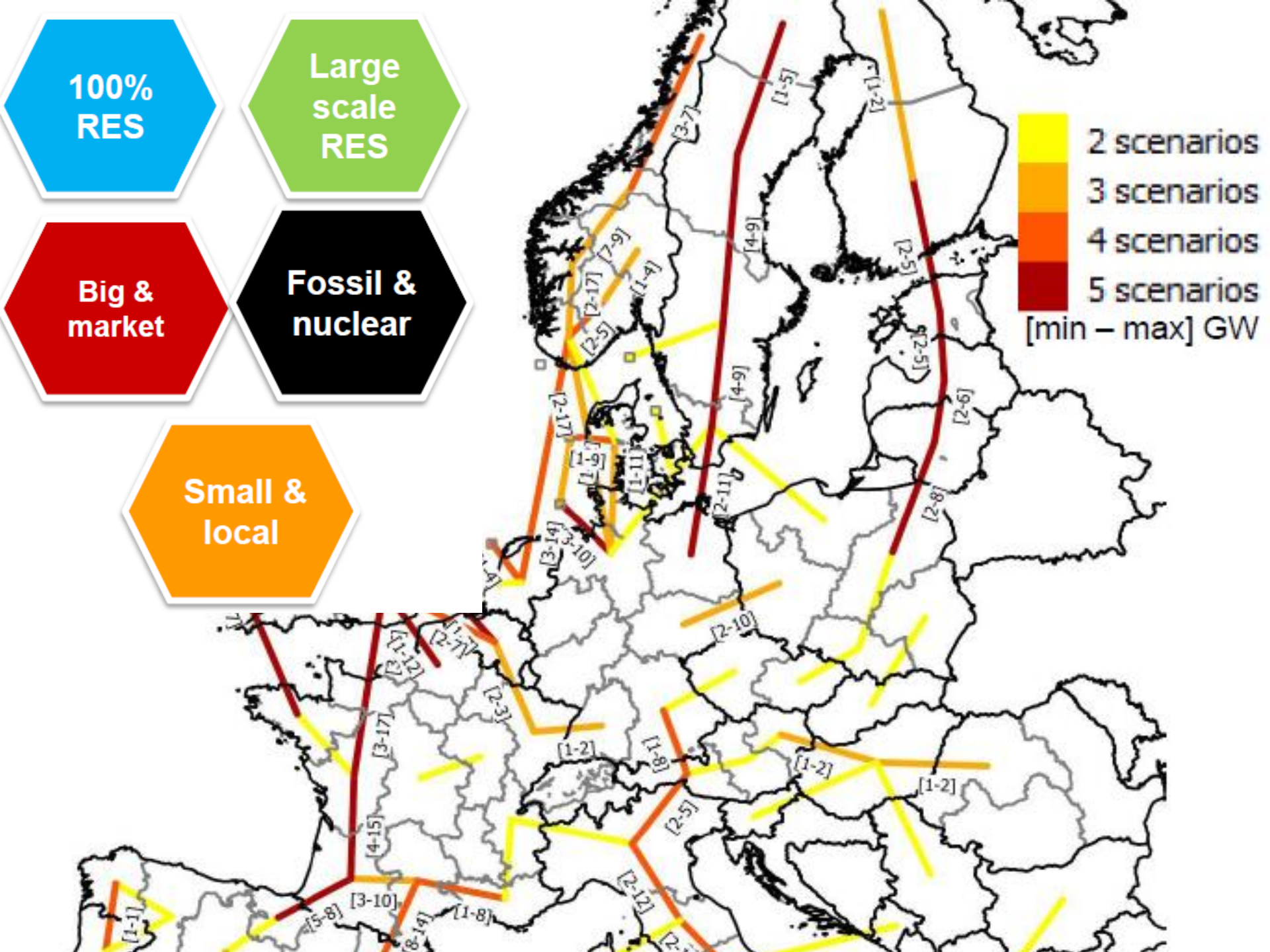
Transmission system demand

19GW

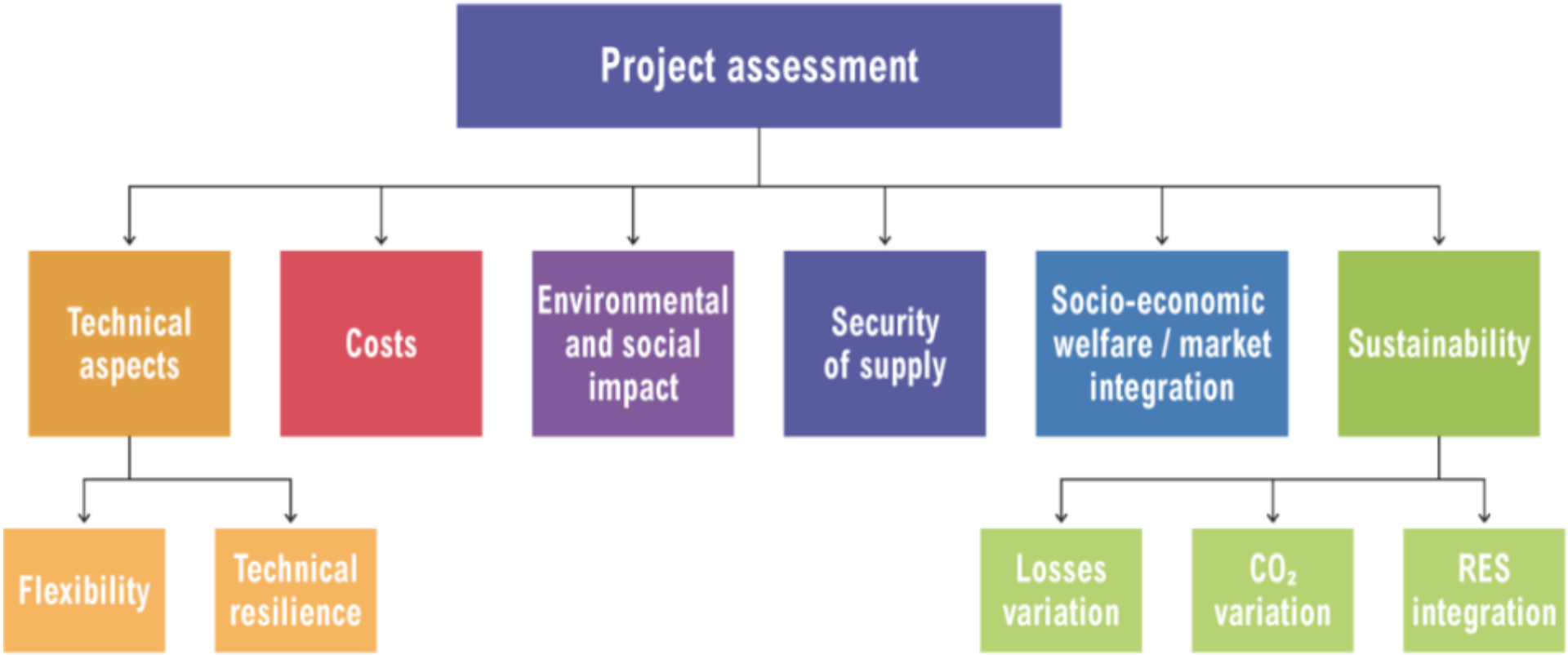
11 August 2014, minimum demand fell to 19GW, which led to 13 consecutive ½ hour periods of negative generation prices.

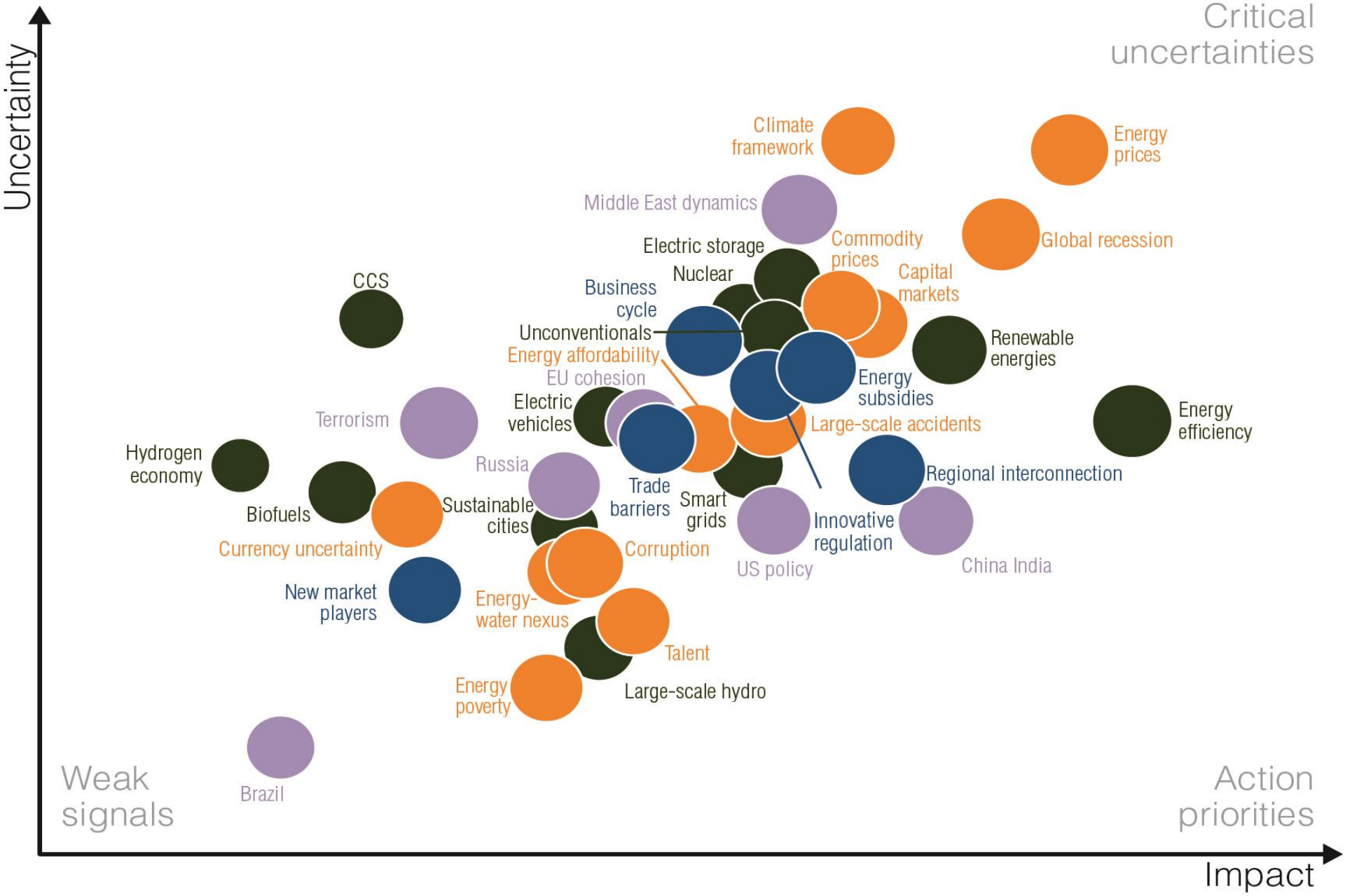
	Gone Green	Slow Progression	No Progression	Consumer Power
Power				
Annual demand, TWh	362	332	333	342
Peak demand, GW	66.1	59.4	60.8	62.6
Total installed capacity, GW	136	117	101	125
Low carbon capacity, GW	98	74	48	76
Interconnector capacity, GW	17.7	14.2	9.8	10.8

Critical Schemes	Network Area	No Progression	Slow Progression	Low Carbon Life	Gone Green	Local Contracted	Decision
Western HVDC Link	Scotland to England border	2016	2016	2016	2016	2016	Complete construction
Series and Shunt Compensation	Scotland to England border	2015	2015	2015	2015	2015	Complete construction
Wylfa–Pentir	North Wales	N/A	N/A	2027	2028	2025	Complete pre-construction consenting
Pentir–Trawsfynndd	North Wales	N/A	2022	2027	2021	2021	Delay
Wymondley Turn-in	South East	N/A	2019	2019	2019	2019	Complete pre-construction
Wymondley QBs	South East	N/A	2019	2019	2019	2019	Complete pre-construction
South Coast Reactive Compensation	South Coast	N/A	2021	2021	2020	2020	Delay
Bramford–Twinstead New Overhead Lines	East Anglia	N/A	2025	2023	2023	2023	Delay
Hinkley–Seabank	South West	2029	2027	2025	2026	2021	Complete pre-construction
Integrated Offshore Transmission Project (East)	Offshore	N/A	N/A	2026	2027	2025	


100% RES
Large scale RES
Big & market
Fossil & nuclear
Small & local
2 scenarios
3 scenarios
4 scenarios
5 scenarios
[min – max] GW

What Makes a Good Project?




Uncertainty
Critical uncertainties
Climate framework
Energy prices
Middle East dynamics
Global recession
Electric storage
Commodity prices
Nuclear
Capital markets
CCS
Business cycle
Unconventionals
Renewable energies
Energy affordability
EU cohesion
Energy subsidies
Terrorism
Electric vehicles
Energy efficiency
Large-scale accidents
Hydrogen economy
Russia
Regional interconnection
Trade barriers
Smart grids
Biofuels
Sustainable cities
Innovative regulation
Currency uncertainty
Corruption
US policy
China India
New market players
Energy-water nexus
Talent
Energy poverty
Large-scale hydro
Brazil
Weak signals
Action priorities
Impact

UHVNET 2016

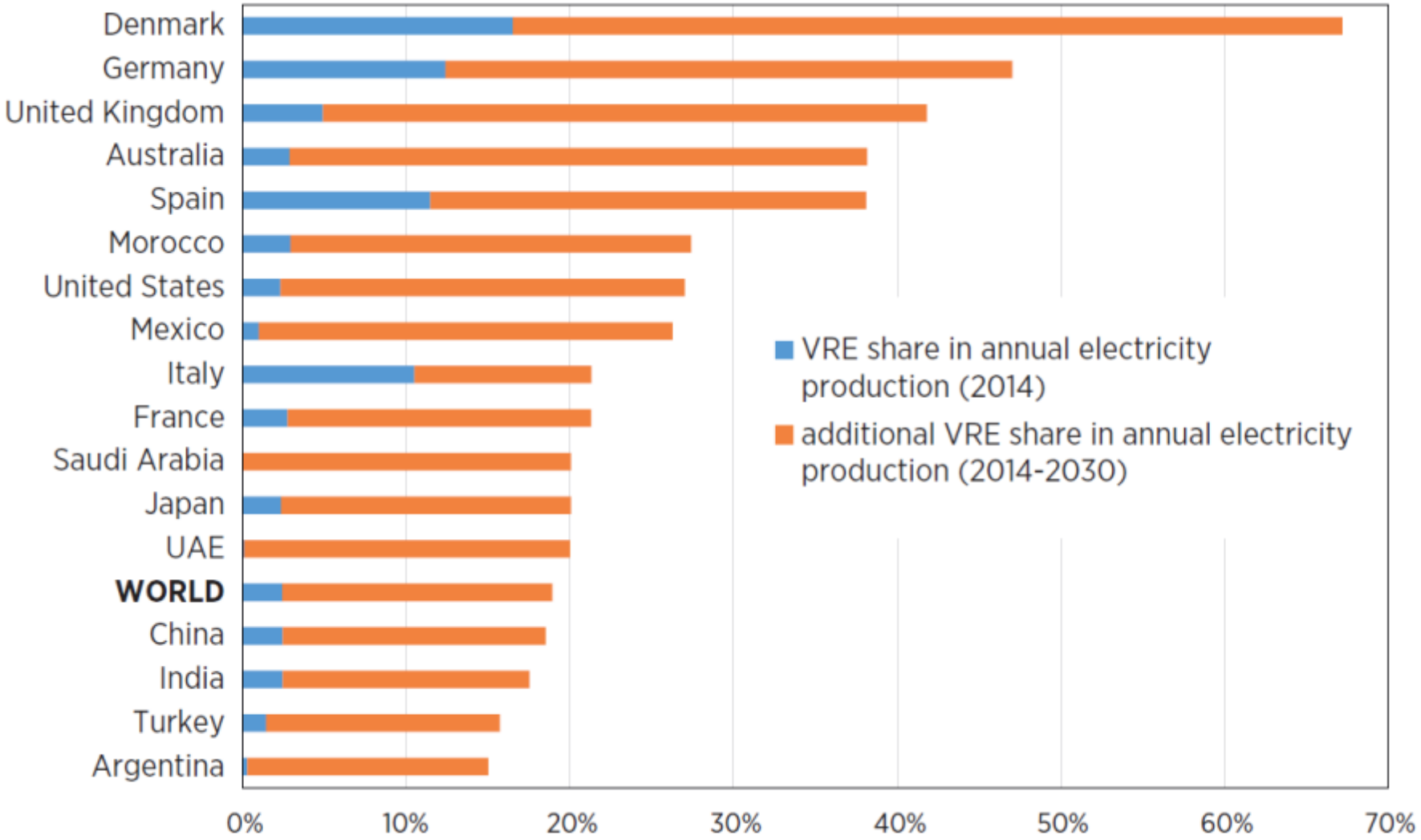

Shale Gas

Renewable Integration

Integration of renewables

- Coping with intermittency
- Changing power flows, congestion . . . .
- Market models
  - Incentives for holding conventional reserve
- Wide(r) area protection, monitoring & control
  - Cross border coordination to balance resources
- Offshore technologies
- Interconnections & storage

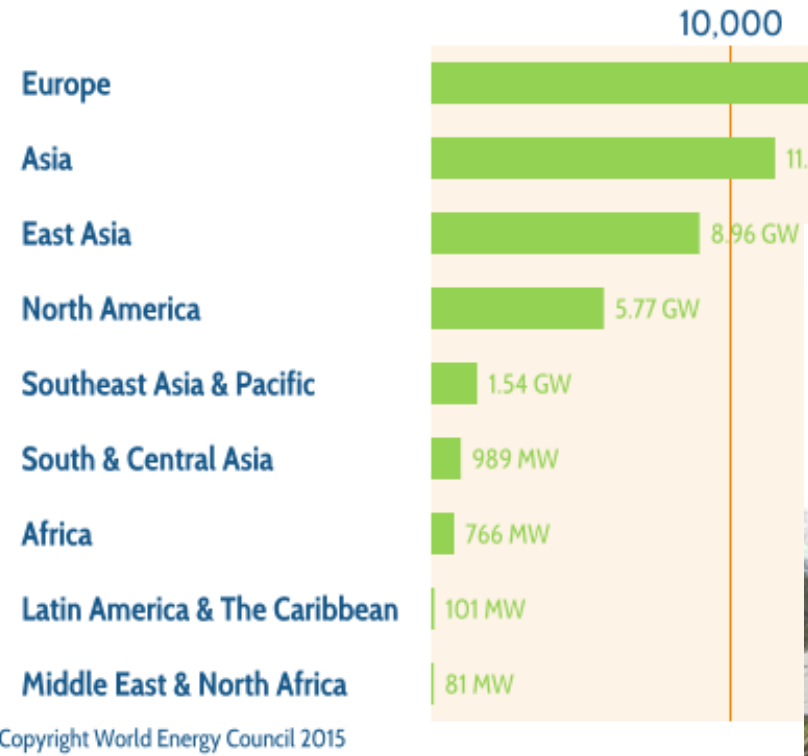
Predicted Growth in Variable Renewable Energy

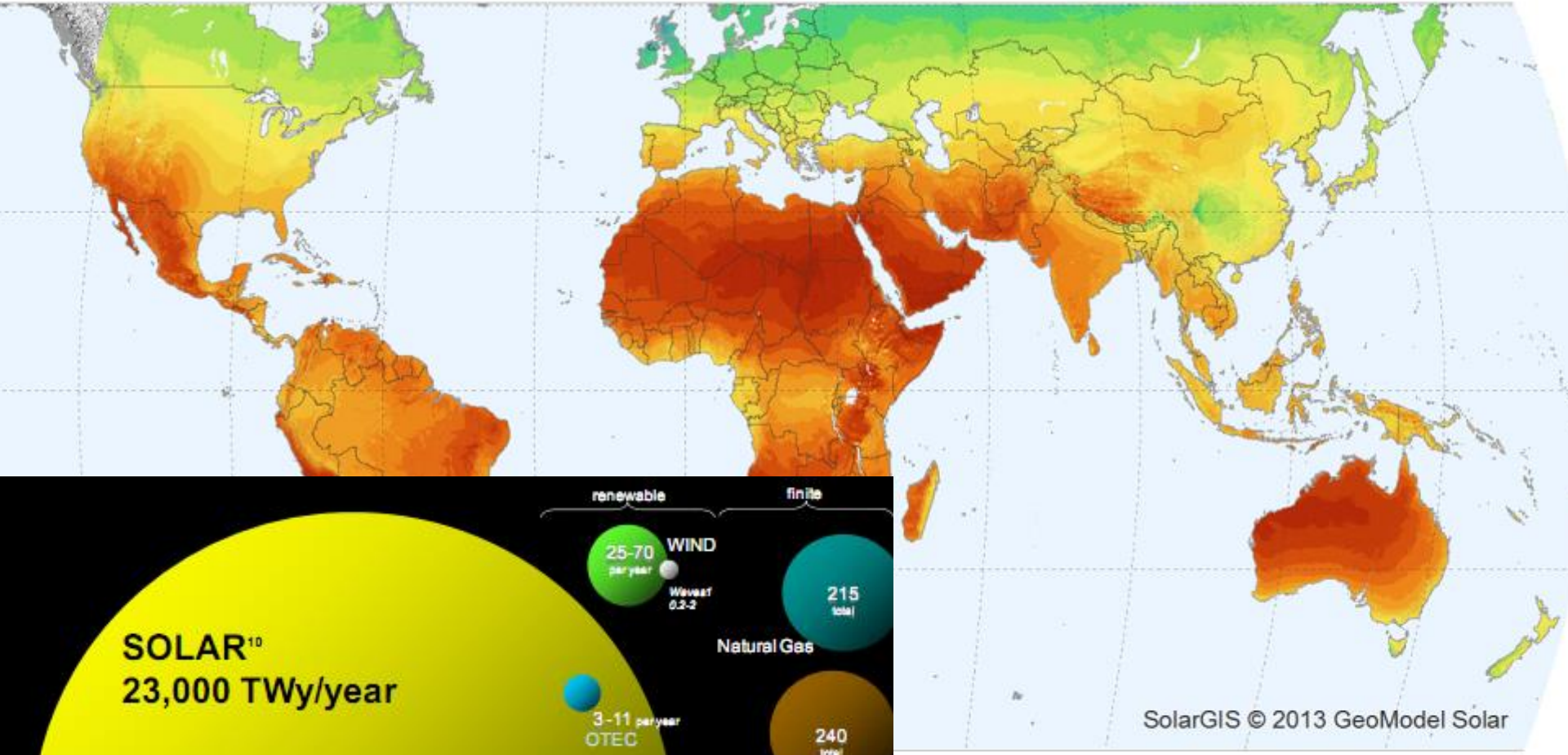


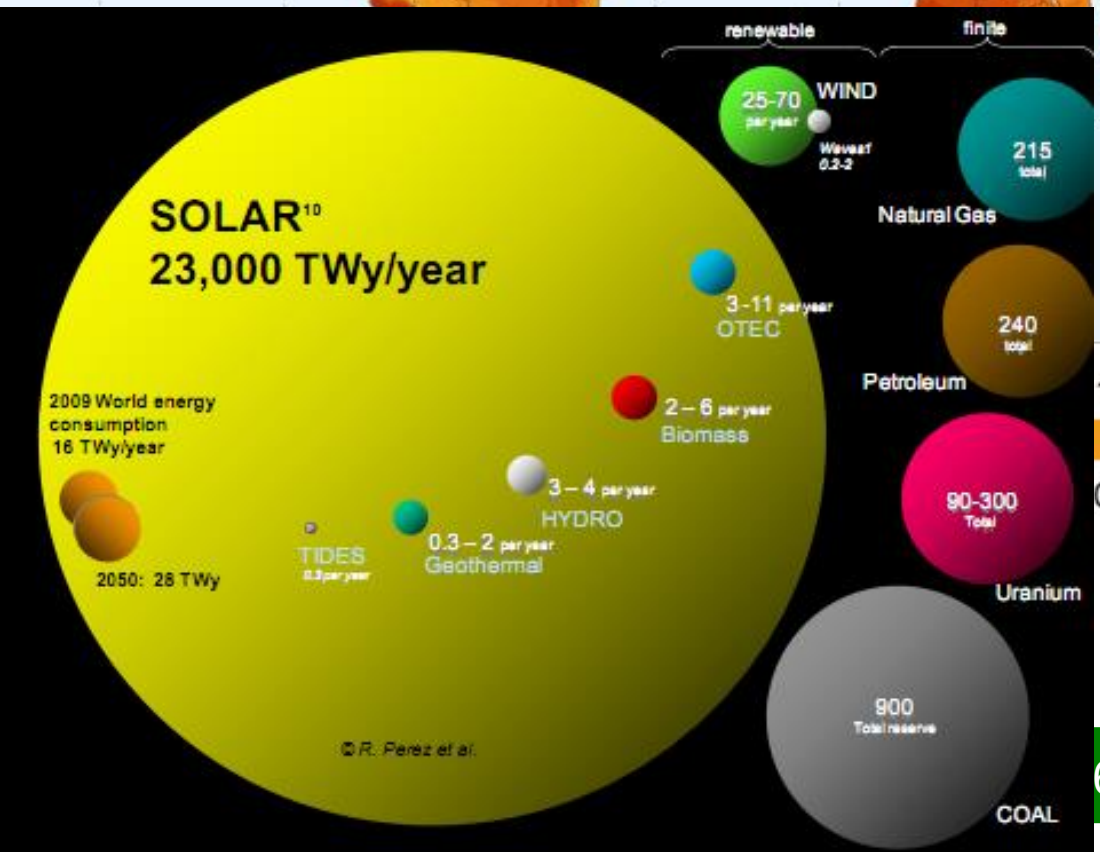
The problem and the solution

Solar exploitation

Solar installed capacity by region



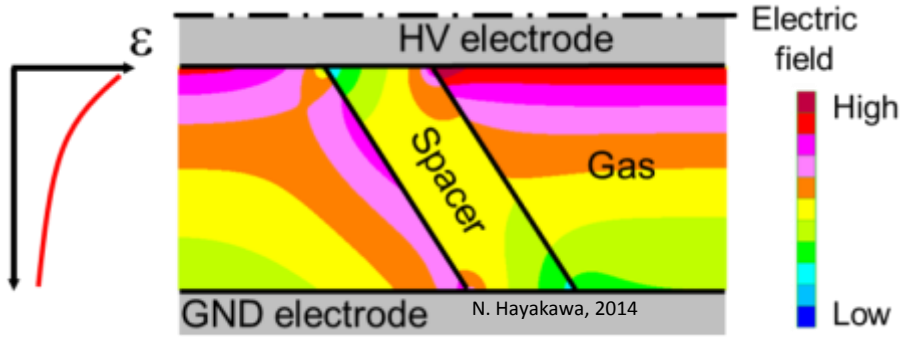

SolarGIS © 2013 GeoModel Solar
1900 2100 2300 2500 2700 >
kWh/m²
0 5.5 6.0 6.5 7.0 7.5 >


renewable
finite
SOLAR[10]
23,000 TWy/year
25-70 per year
WIND
Wavest 0.2-2
215 total
Natural Gas
3-11 per year
OTEC
240 total
Petroleum
2009 World energy consumption 16 TWy/year
2 – 6 per year
Biomass
3 – 4 per year
HYDRO
90-300 Total
Uranium
2050: 28 TWy
TIDES 0.3 per year
0.3 – 2 per year
Geothermal
900 Total reserve
COAL
© R. Perez et al.

Interconnections & Bulk Transportation

Bulk transportation & Interconnection

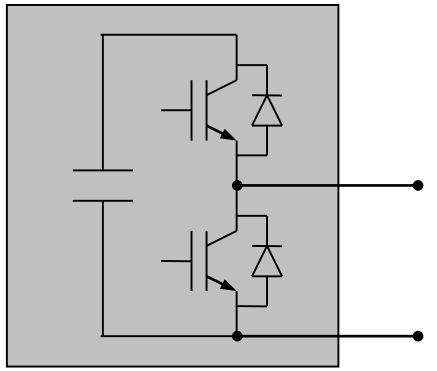
- Connect remote generation to load
- HV technological advancements
  - Higher voltages
  - Corridor usage
- Materials
  - Field grading
- Testing techniques
- Greater integration
- System resilience to loss of connections
- Standardisation

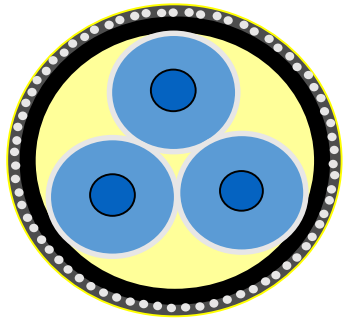


HVAC for 1100/1200kV

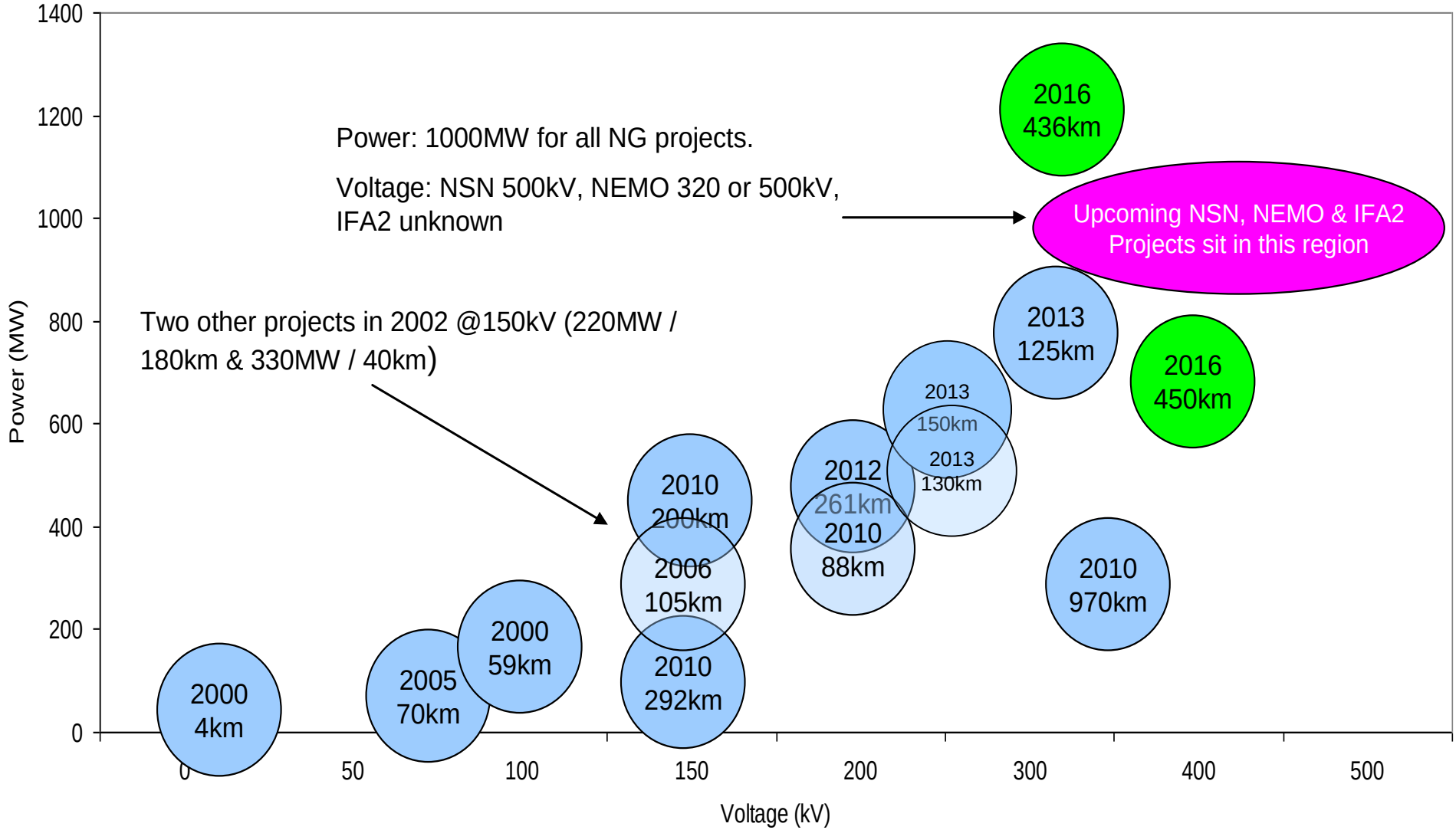
HVDC, DC Grids & Power Electronics

- HVDC converters of larger capacity
  - Increasing voltages; 800kV to 1100kV
  - Higher power ratings; 6000MW to 10,000MW
  - Increasing capability of VSC
- Multi-terminal HVDC
- DC switching: circuit breakers, VSC blocking . . .
- Materials for & design of DC GIS & GIL
- Polymer (XLPE) cables for higher voltages
- Fast, discriminating protection schemes for multi-terminal
- Control of HVDC embedded in parallel with AC network
- Standardisation & interoperability
- Offshore installation vessels and techniques

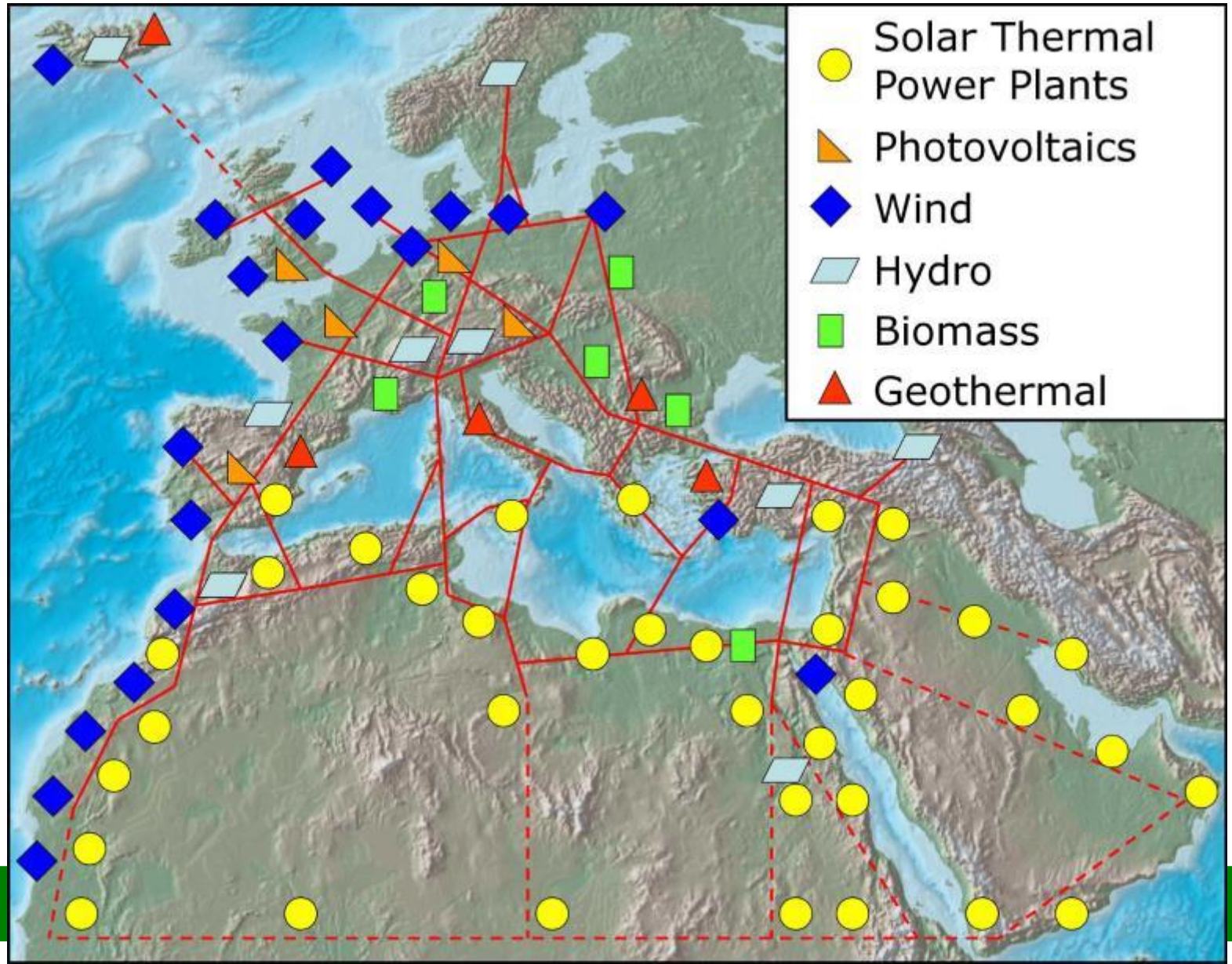




VSC advances

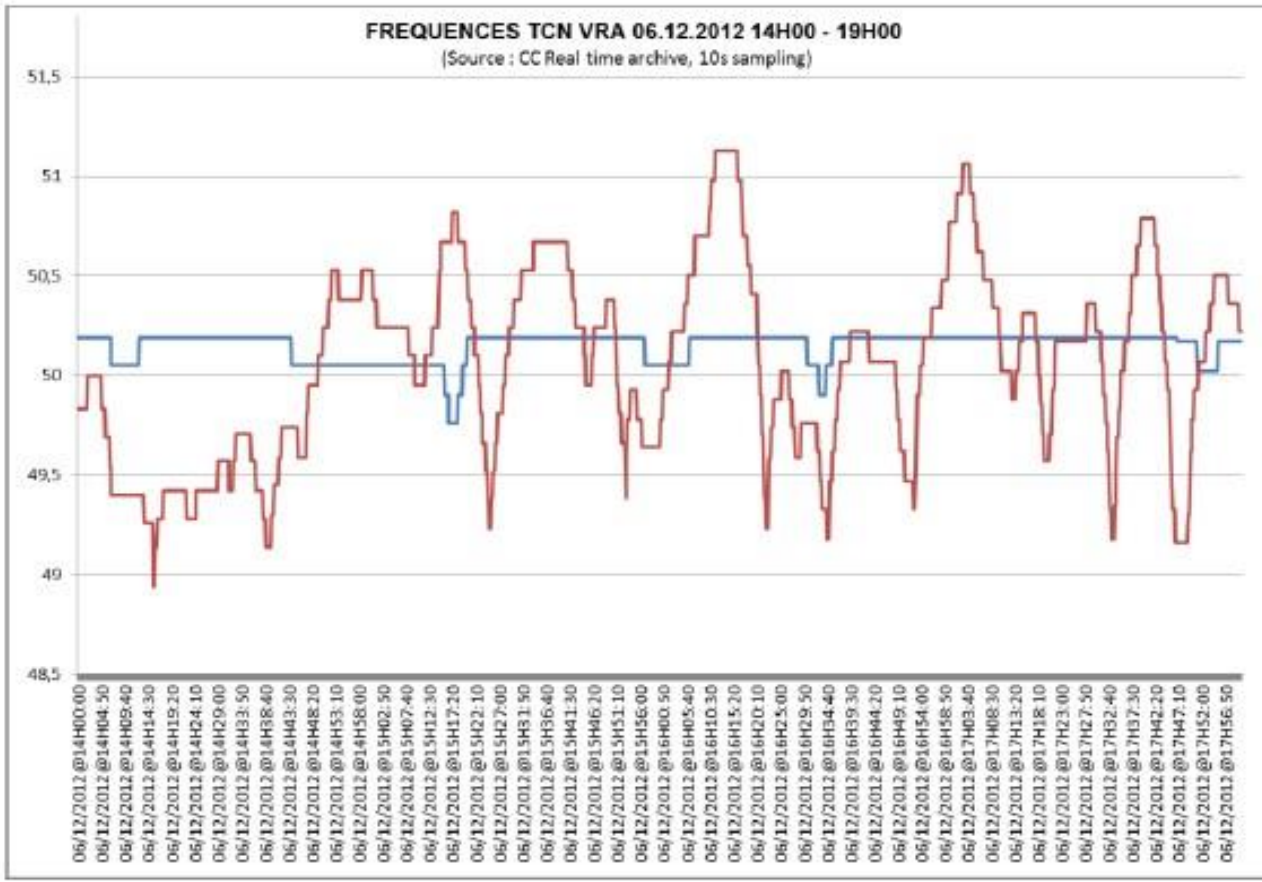


European interconnected grid

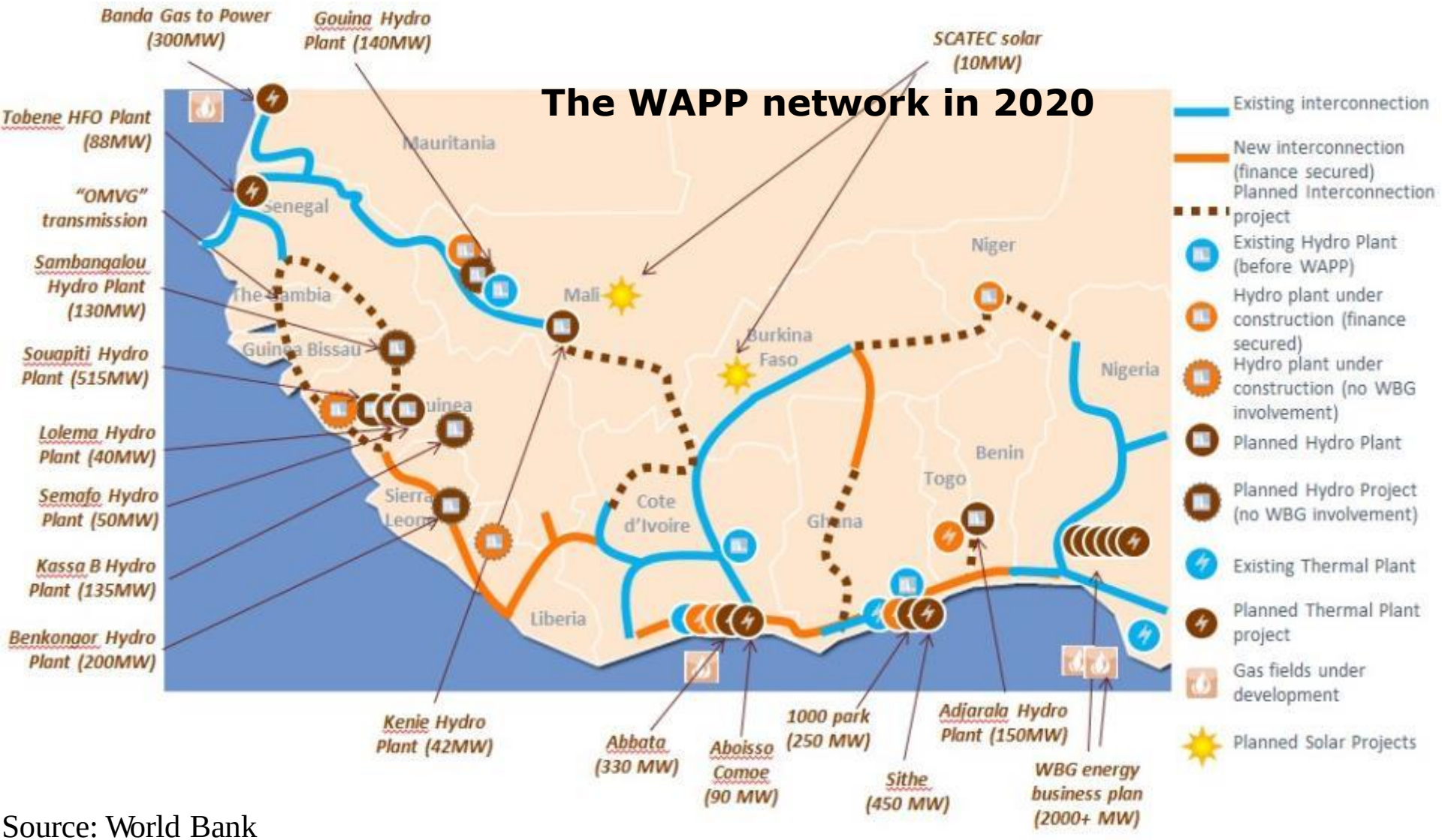


Africa

- Vast potential
- Interconnection required
- Rural remote areas need solutions
- Western Grid vs Nigeria



WAPP 2020



Source: World Bank

Limitless Ambition

Storage

ENERGY STORAGE

Mechanical

- Pumped Hydro (PHS)
- Compressed Air Energy Storage (CAES)
- Flywheel

Electrochemical

- Conventional Batteries (Lead acid / NiCd / NiMh / Li)
- High Temperature (NaS / NaNiCl)
- Flow Batteries (Redox flow / Hybrid flow)

Electrical

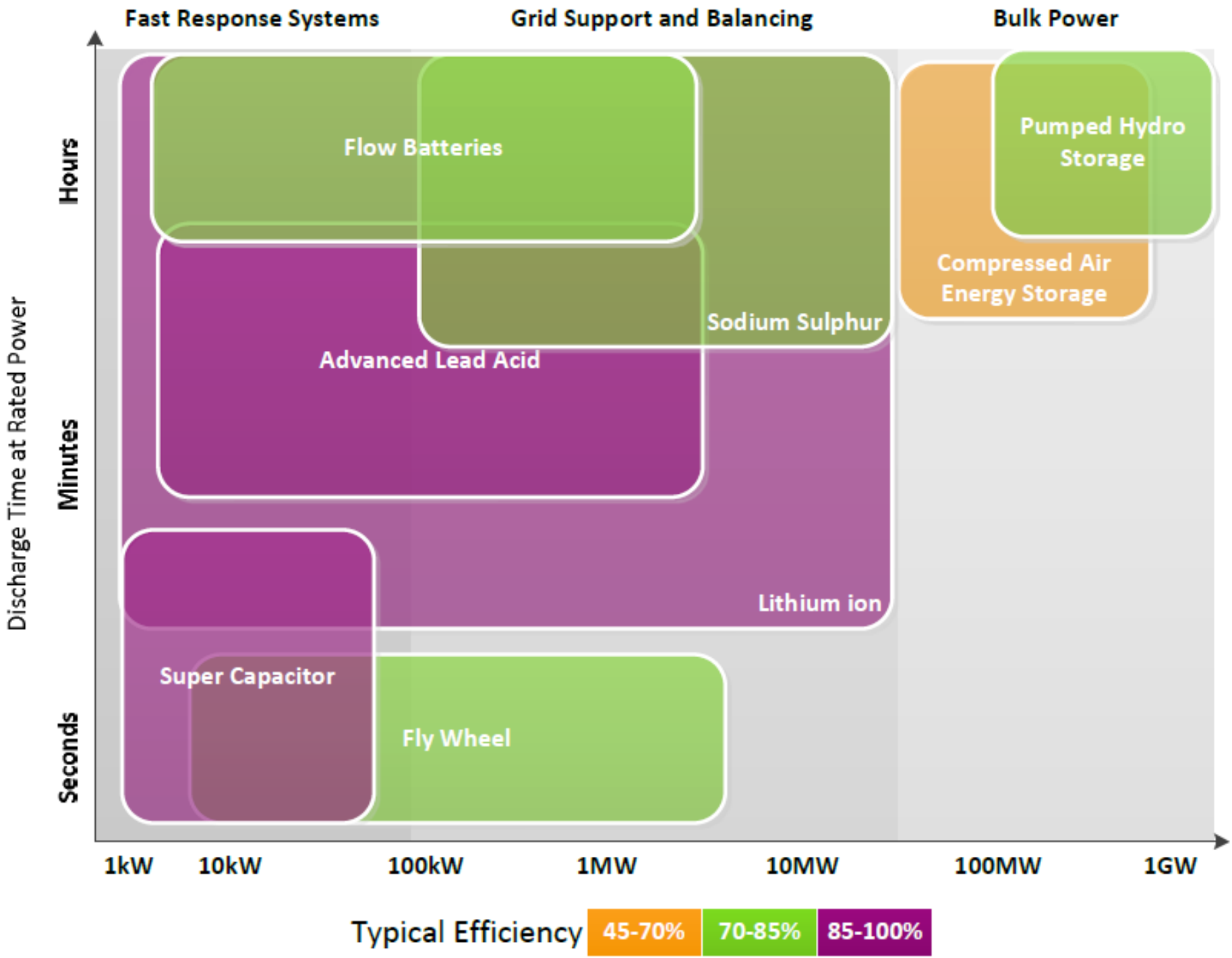
- Capacitors
- Superconductors

Chemical

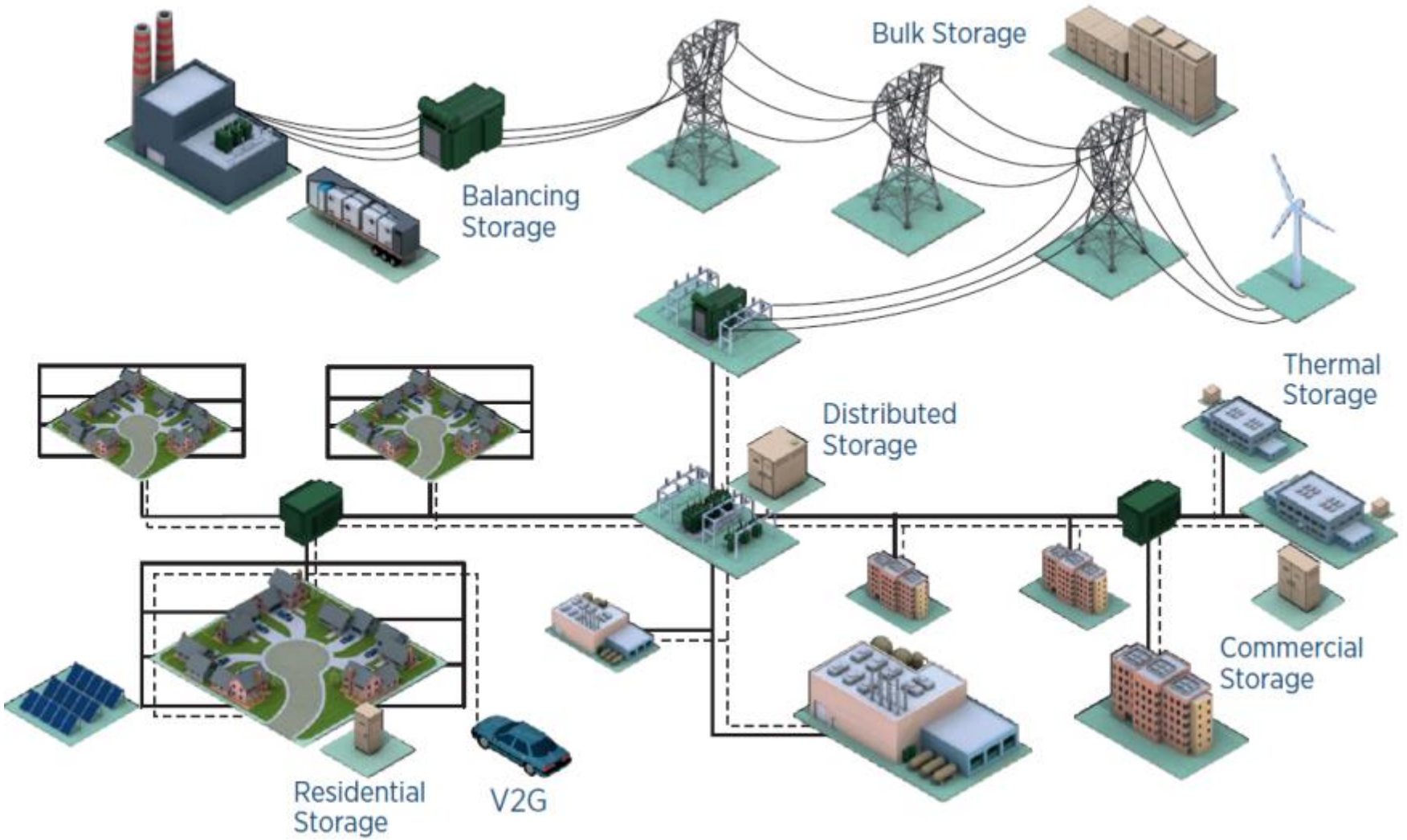
- Hydrogen
- Methane

Thermal

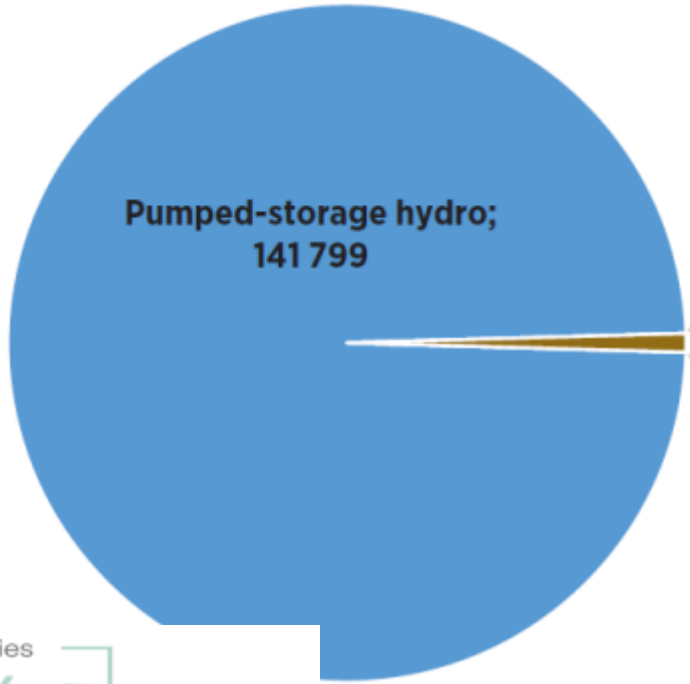
- Molten Salts
- Chillers

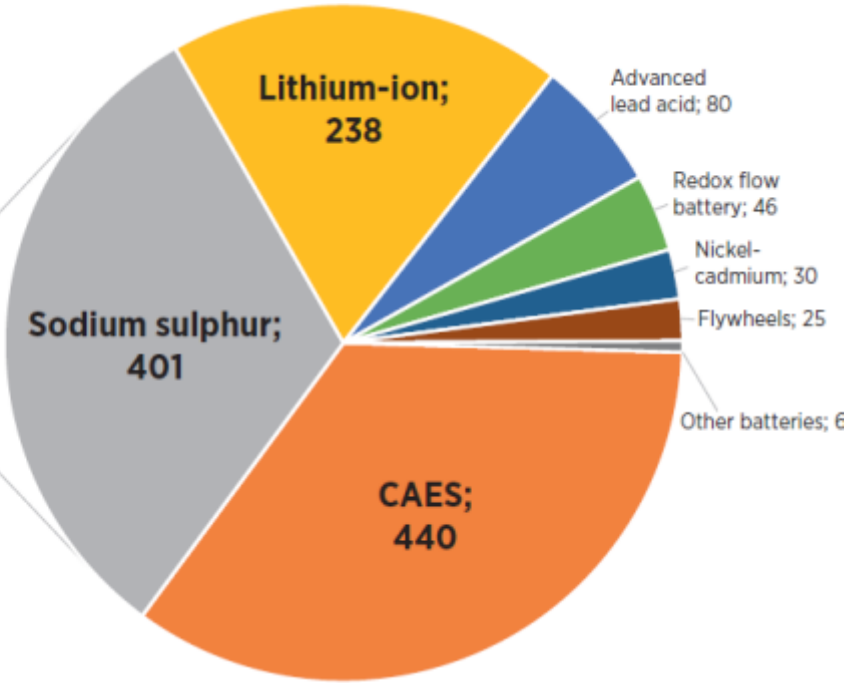

Fast Response Systems
Grid Support and Balancing
Bulk Power
Discharge Time at Rated Power
Hours
Minutes
Seconds
Flow Batteries
Pumped Hydro Storage
Compressed Air Energy Storage
Sodium Sulphur
Advanced Lead Acid
Lithium ion
Super Capacitor
Fly Wheel
1kW
10kW
100kW
1MW
10MW
100MW
1GW
Typical Efficiency
45-70%
70-85%
85-100%

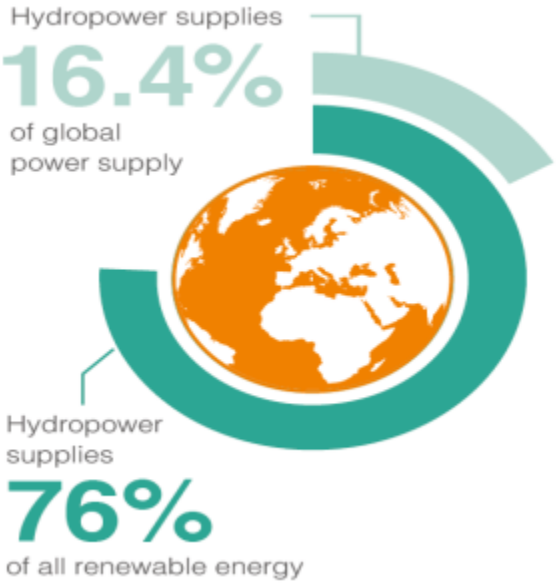
The Vision


Bulk Storage
Balancing Storage
Thermal Storage
Distributed Storage
Commercial Storage
Residential Storage
V2G

Present day reality





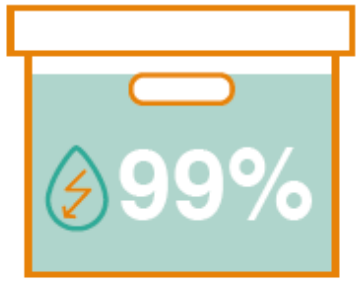


Hydropower reached

1000GW

of total installed capacity, presenting about **half** of undeveloped potential capacity

Storage hydropower (including pumped storage) represents 99% of the world's operational electricity storage

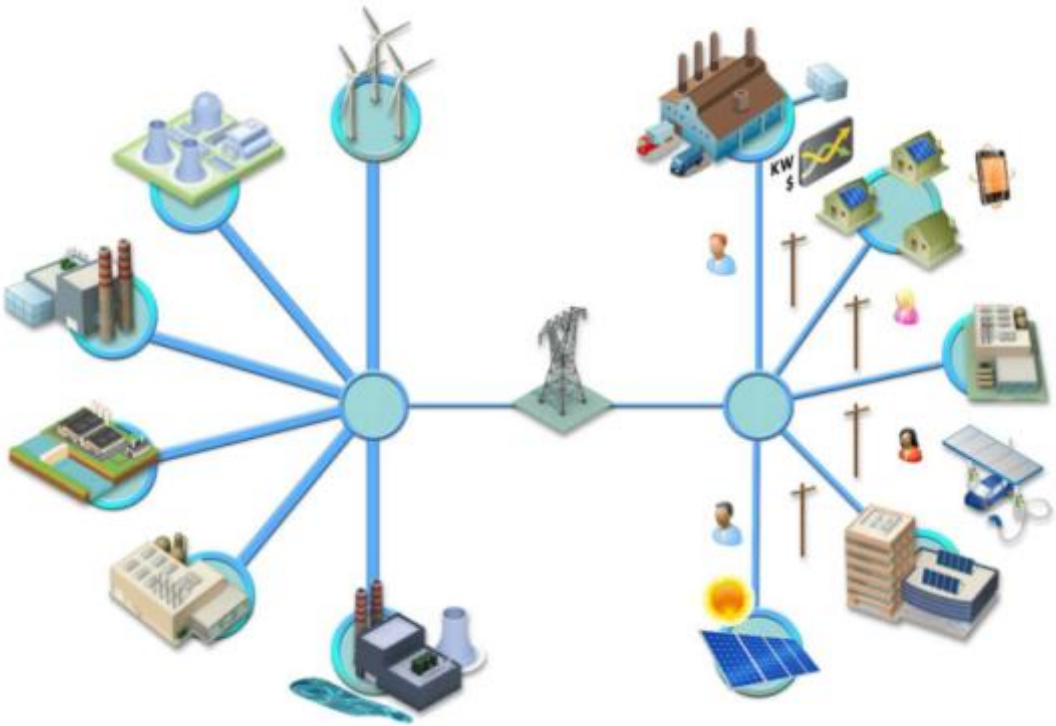


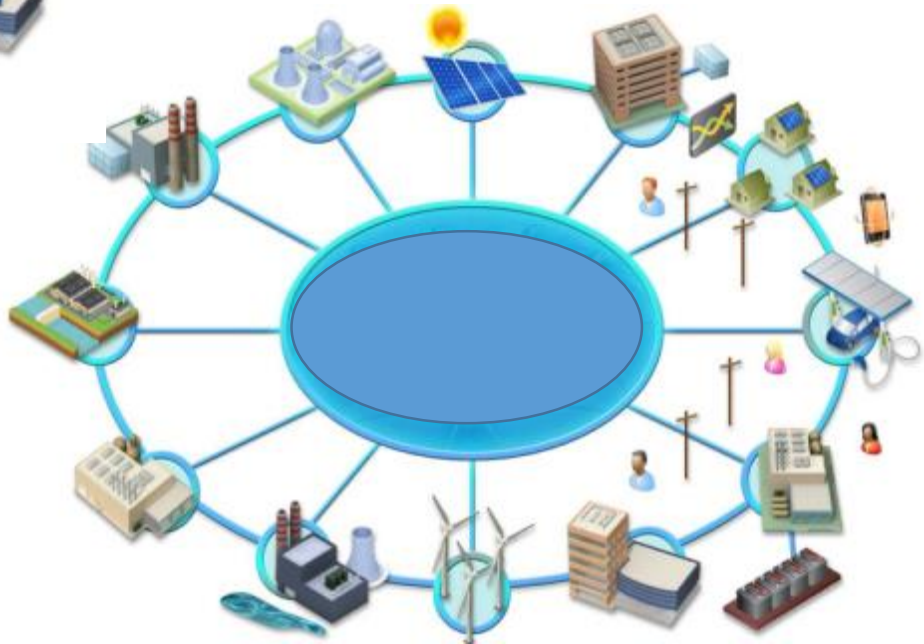
SMART T&D

SMART & Microgrids

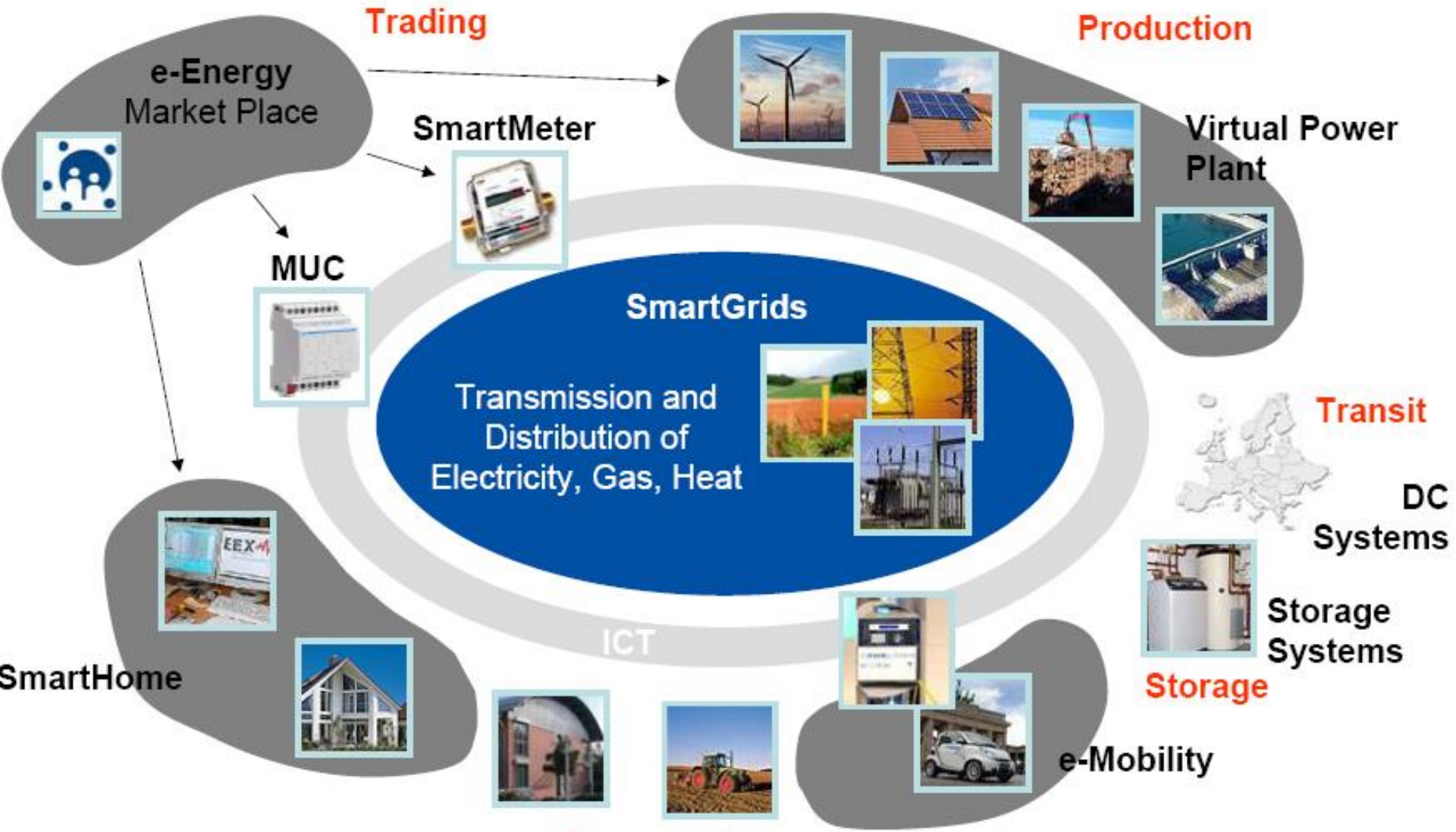
- Migration from passive to active distribution, two way power-flows
- Merging of transmission, distribution & customer
- Smart meters & associated communication
- Wide area control, supervision, protection
- Network & control centre architecture
- Data security, cyber security
- Customer engagement & choices
- Many, many participants
- Off-grid systems (rural electrification)
- LVDC networks

From this . . . . . .to this



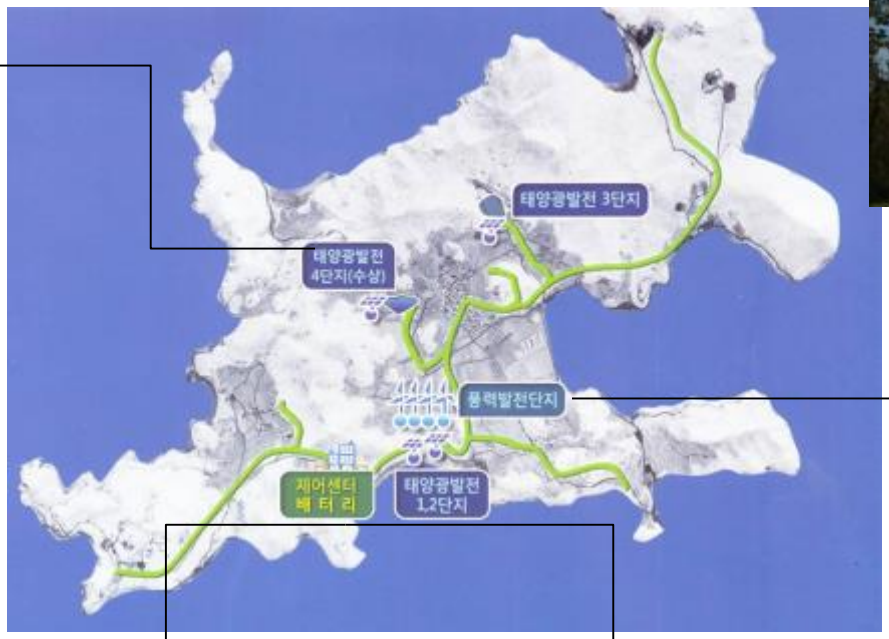


Smartgrid vision

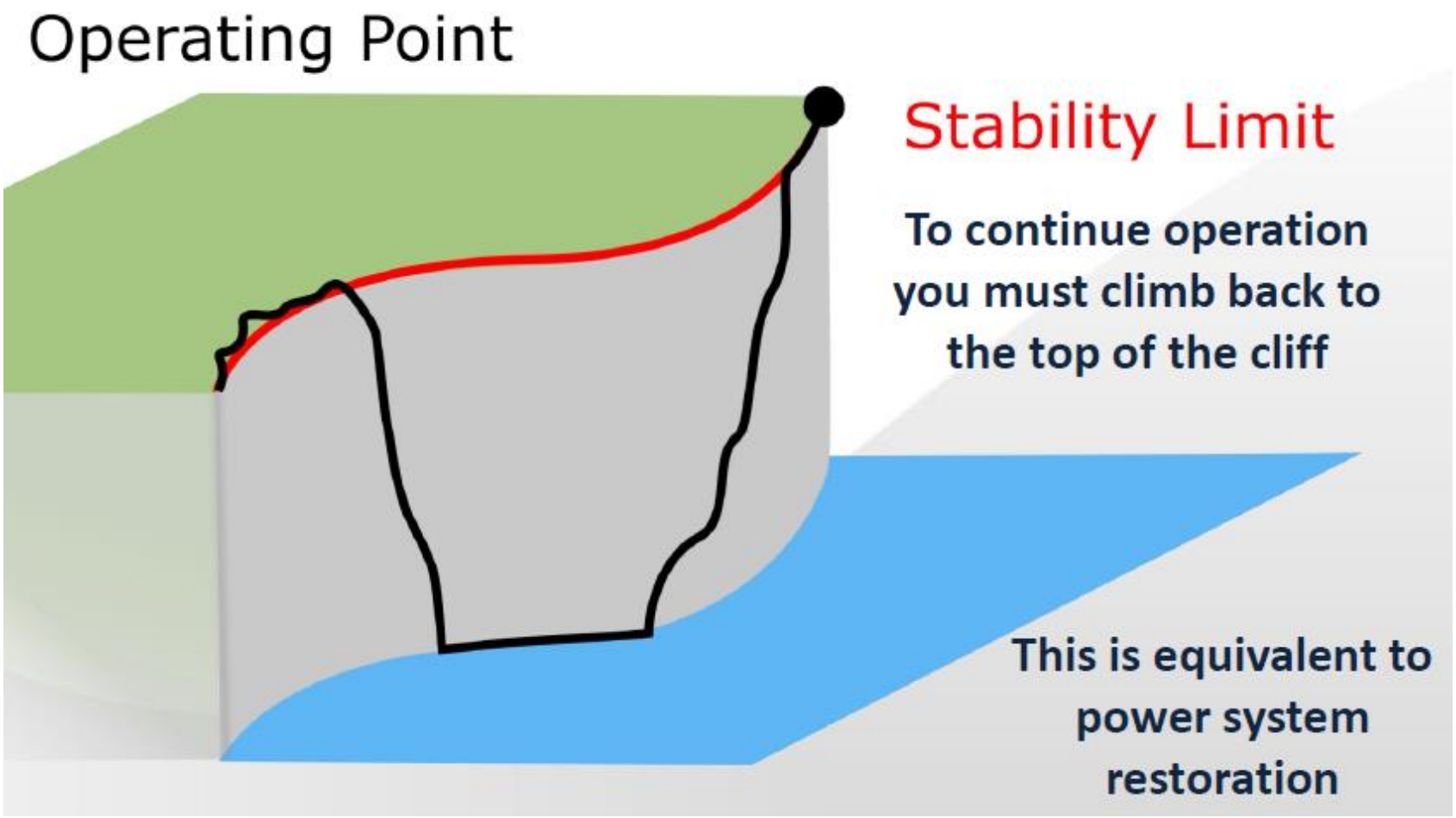


MUC = Multi Utility Communication

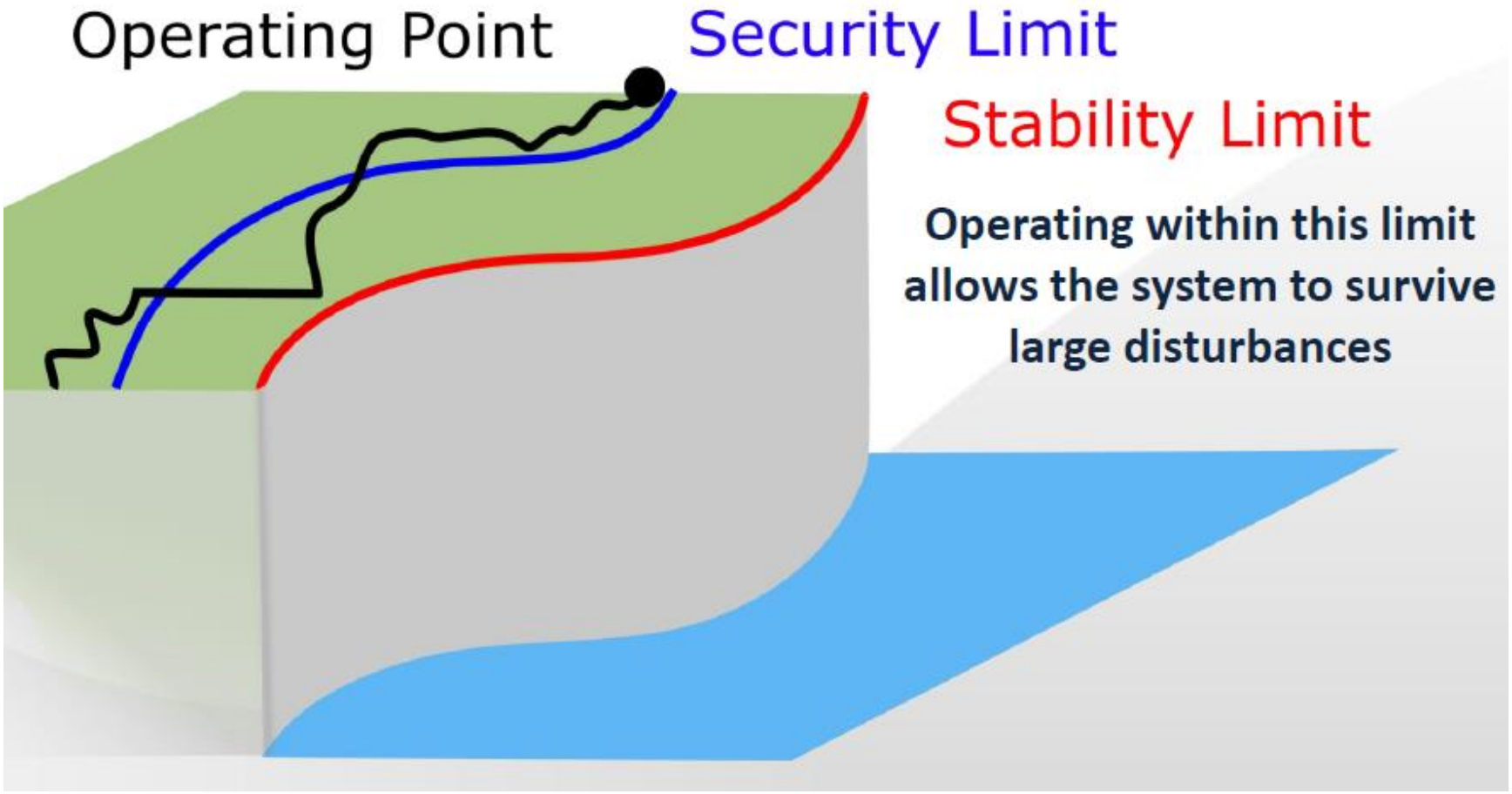
Gasado Island Microgrid



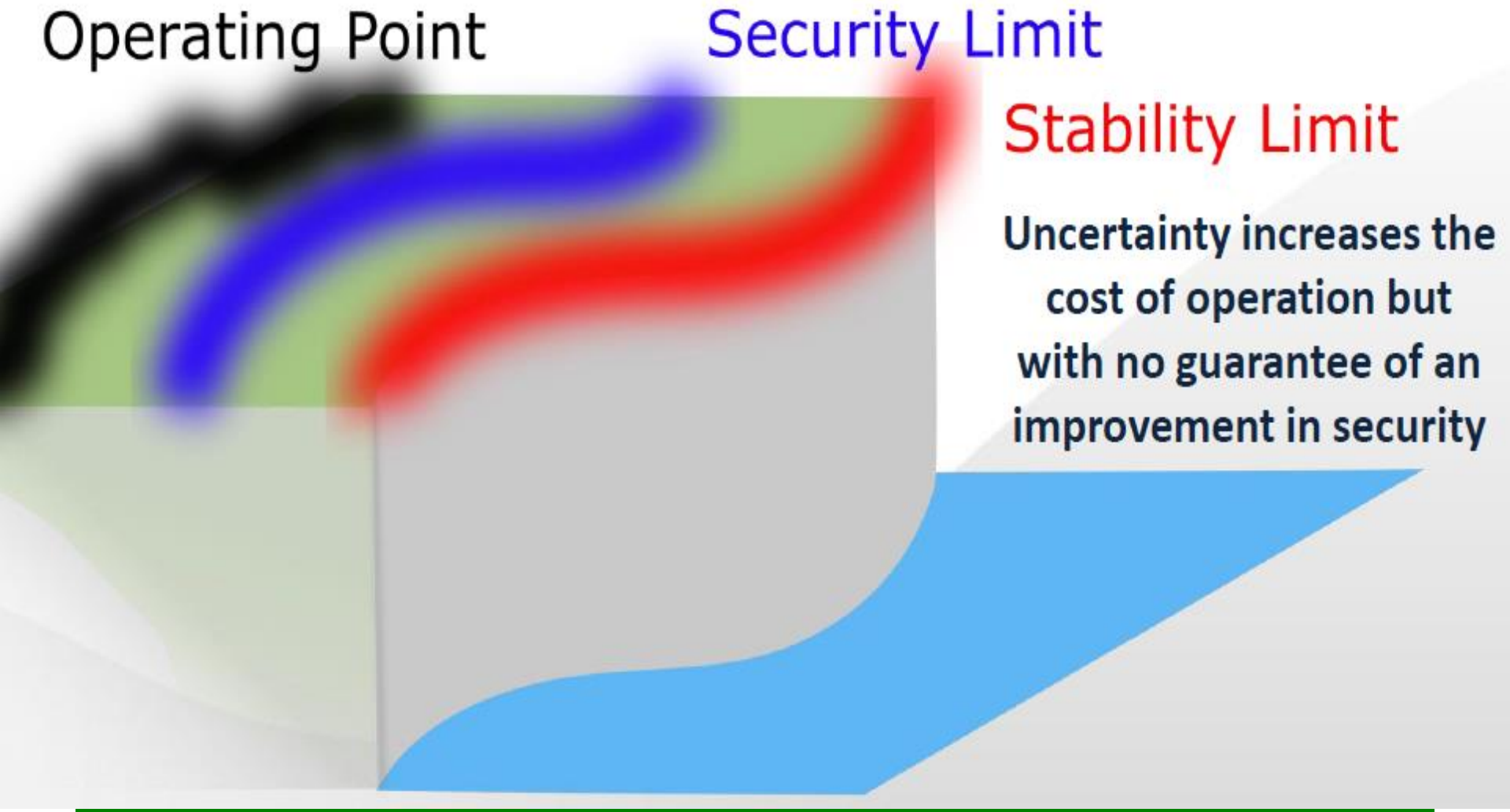
Operating uncertainty (1)



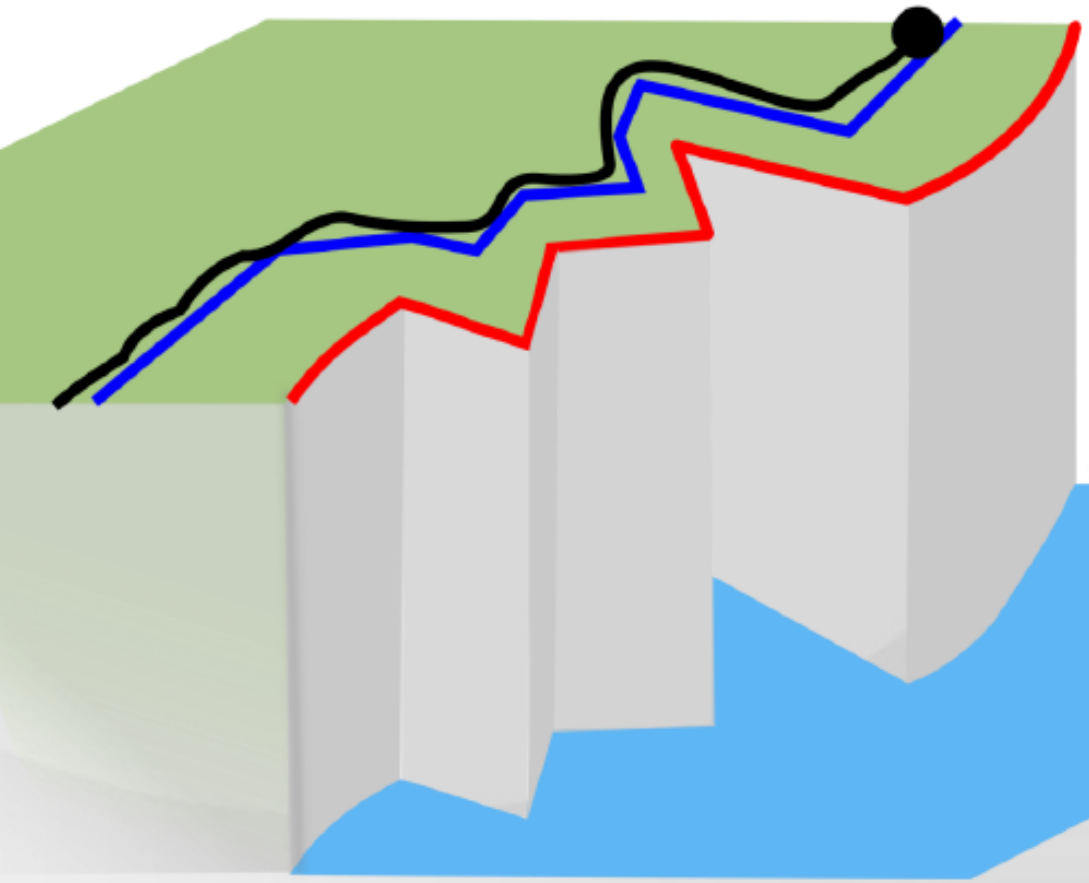
Operating uncertainty (2)



Operating uncertainty (3)

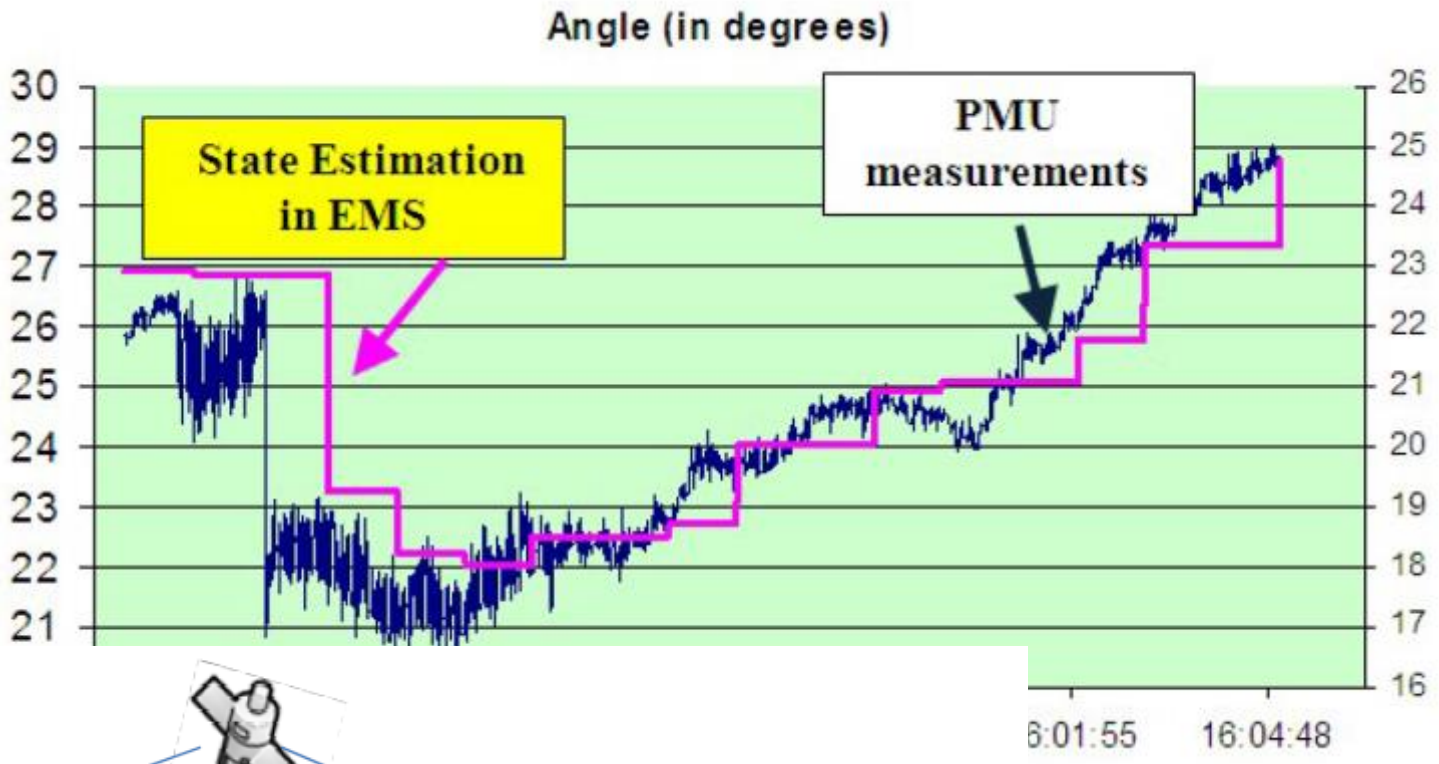


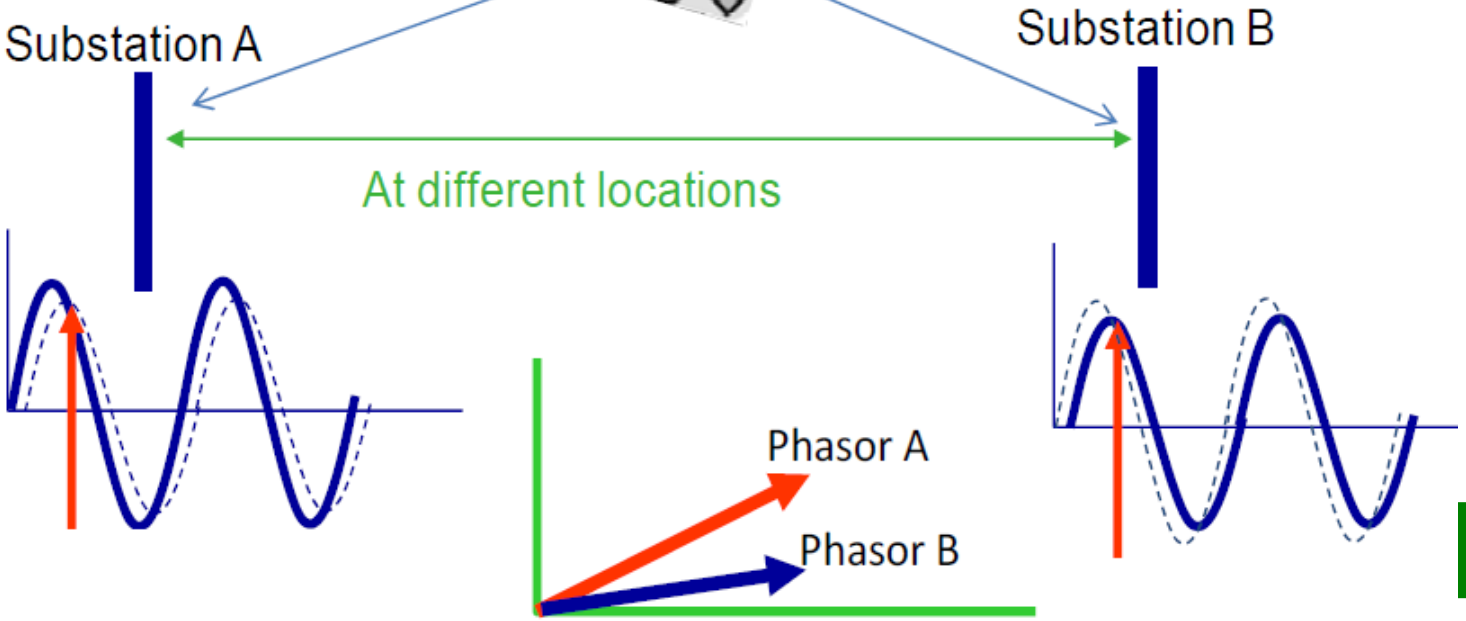
Operating uncertainty (4)



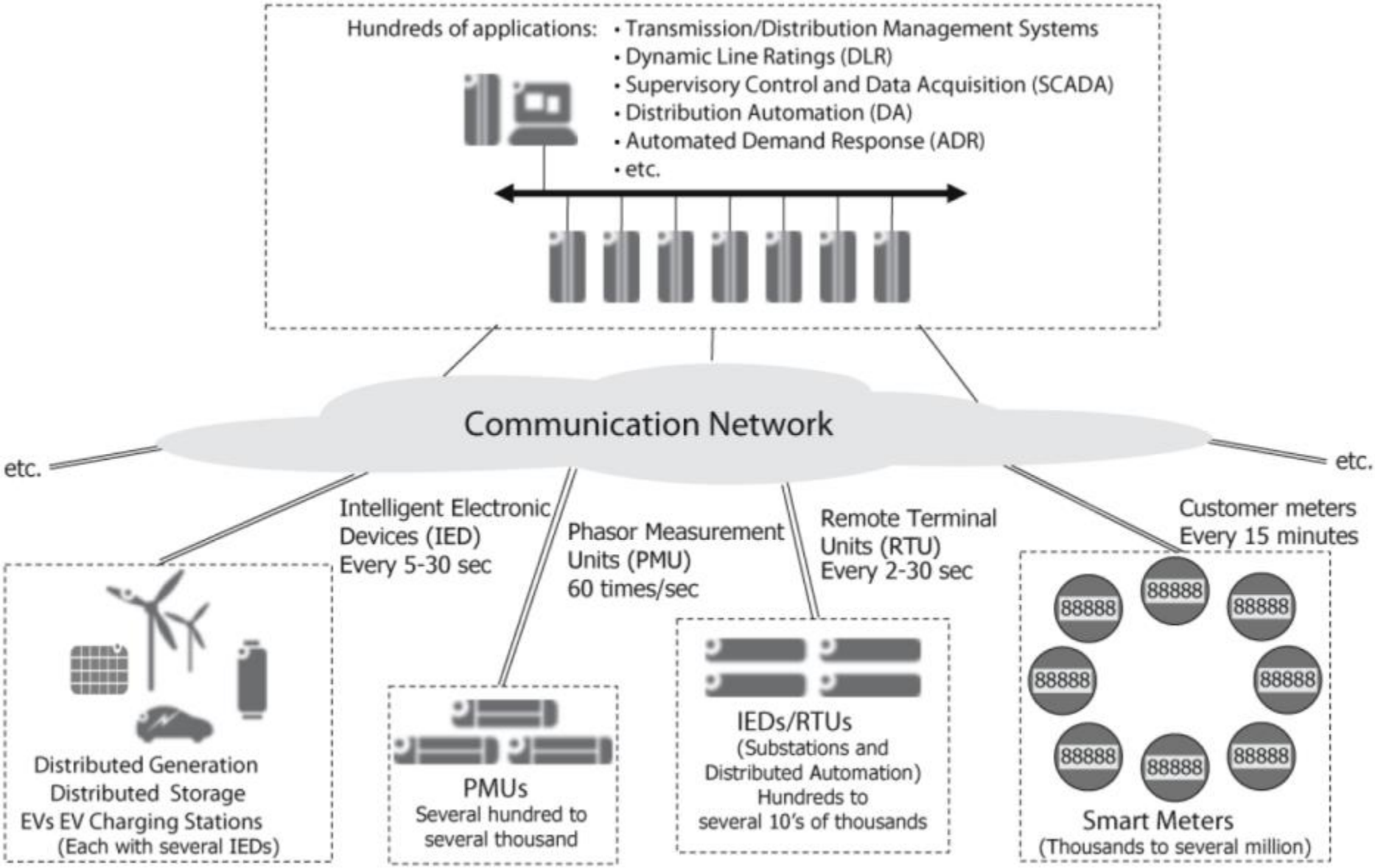
Enhanced control tools are necessary to allow operators exploit these enhanced limits and use the true capacity

Without these tools to complement the new limits the benefit may be limited


Angle (in degrees)
State Estimation in EMS
PMU measurements
30
29
28
27
26
25
24
23
22
21
26
25
24
23
22
21
20
19
18
17
16
6:01:55
16:04:48


Substation A
Substation B
At different locations
Phasor A
Phasor B

Wide area architecture



Evolution of wide area technology

1 Post-disturbance analysis

3 Wide area angular monitoring and alarming

4 Wide area Frequency monitoring

5 Wide area voltage monitoring

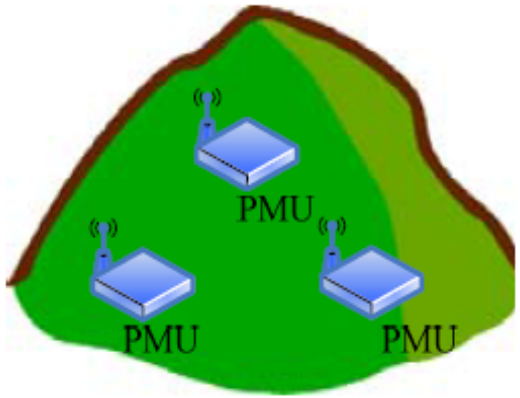
6 Inter-area oscillation monitoring

7 Real time dynamic rating of transmission lines

2 Benchmarking, Validation and Fine-tuning of System Models

8 Adaptive system restoration

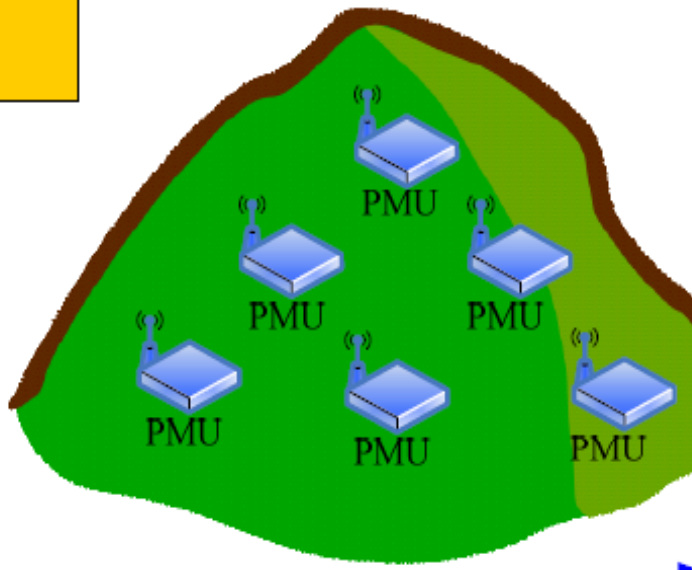
9 Improved state estimation



10 Lincar state cstimation

11 Real time wide area protection

12 Real time wide area control



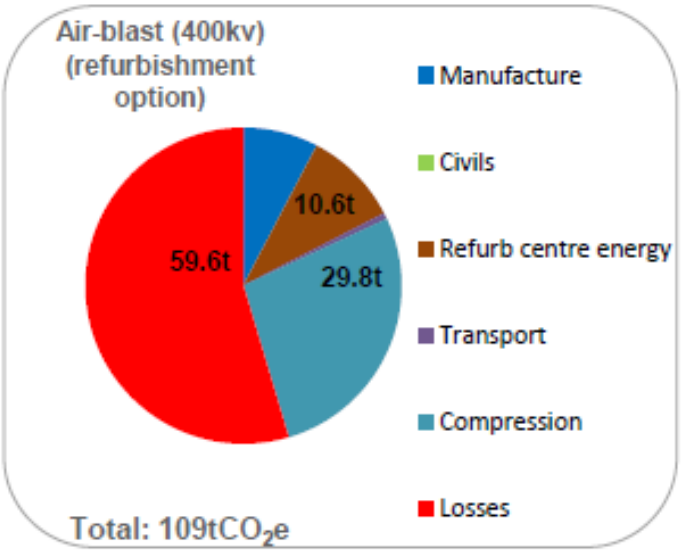
1-3 years **3-5 years** **5-10 years**

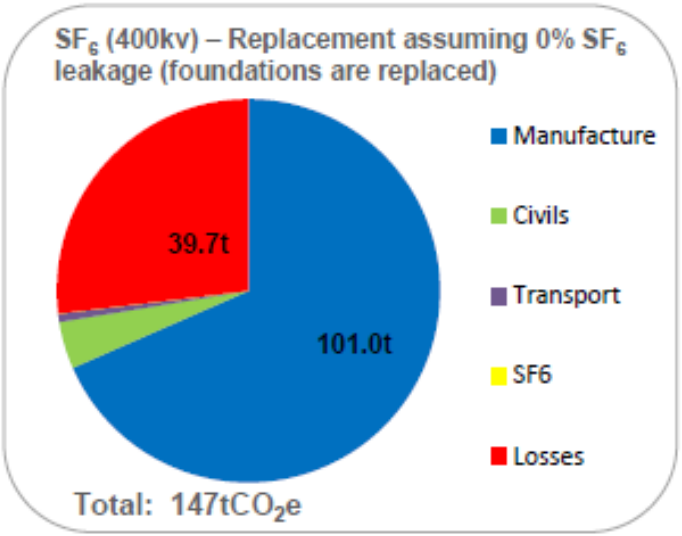
Sustainability and Environment

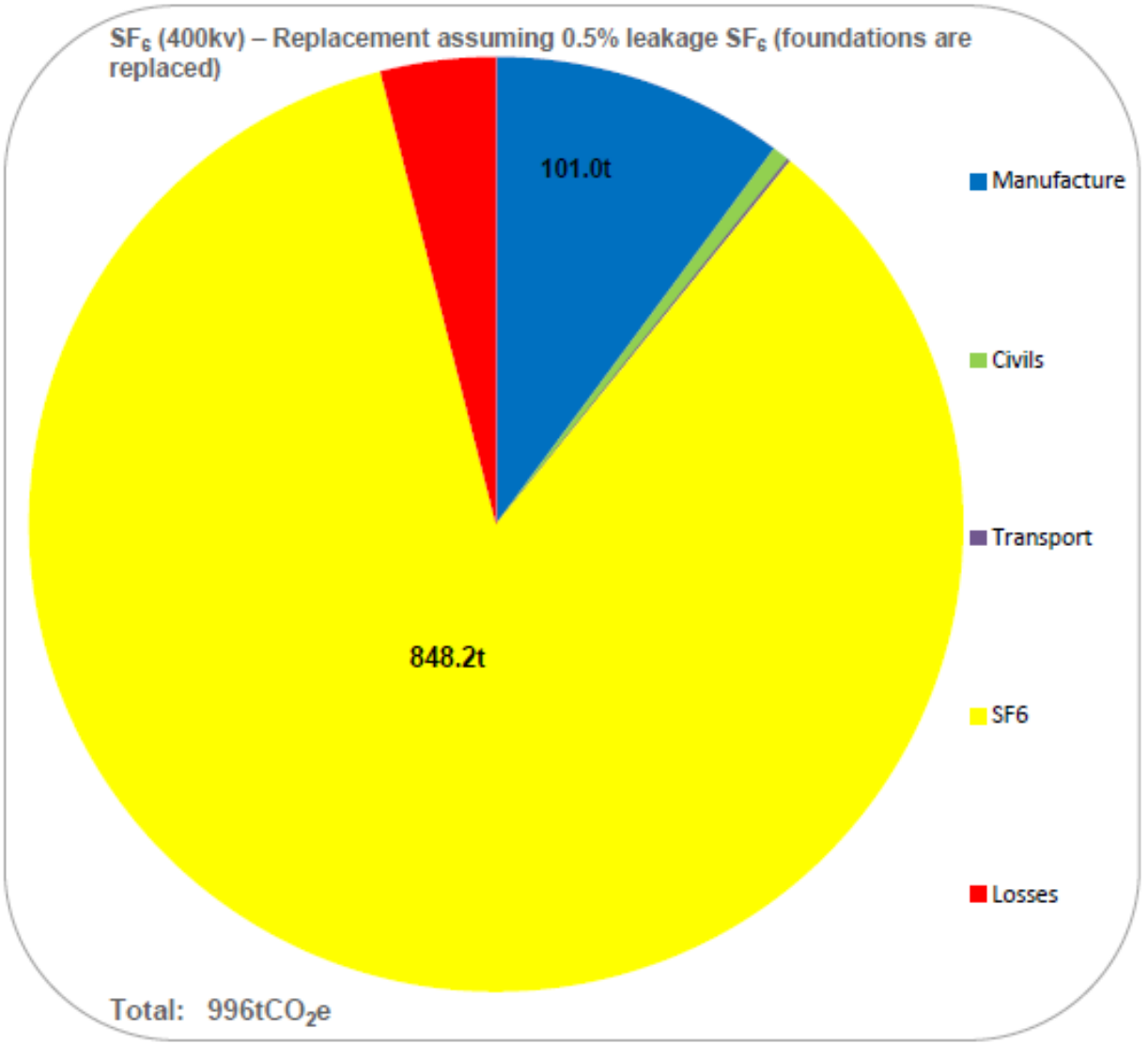
Sustainability

- Global environmental trends
- Renewable sources (hydro, wind, PV, wave)
- Ongoing role of fossil fuels – efficient/clean
- Reduced wastage & energy efficiency
- Transport energy rather than fuels
- Material choices
- Biodegradable, fire retardant, field grading
- Managing public impacts & perceptions
- Climate change/Climatic extremes
- Assessment methodologies
- SF6 management & targeted elimination
  - SF6 free equipment
  - Best practice management of inventory

Lifetime impact of SF_6 leakage

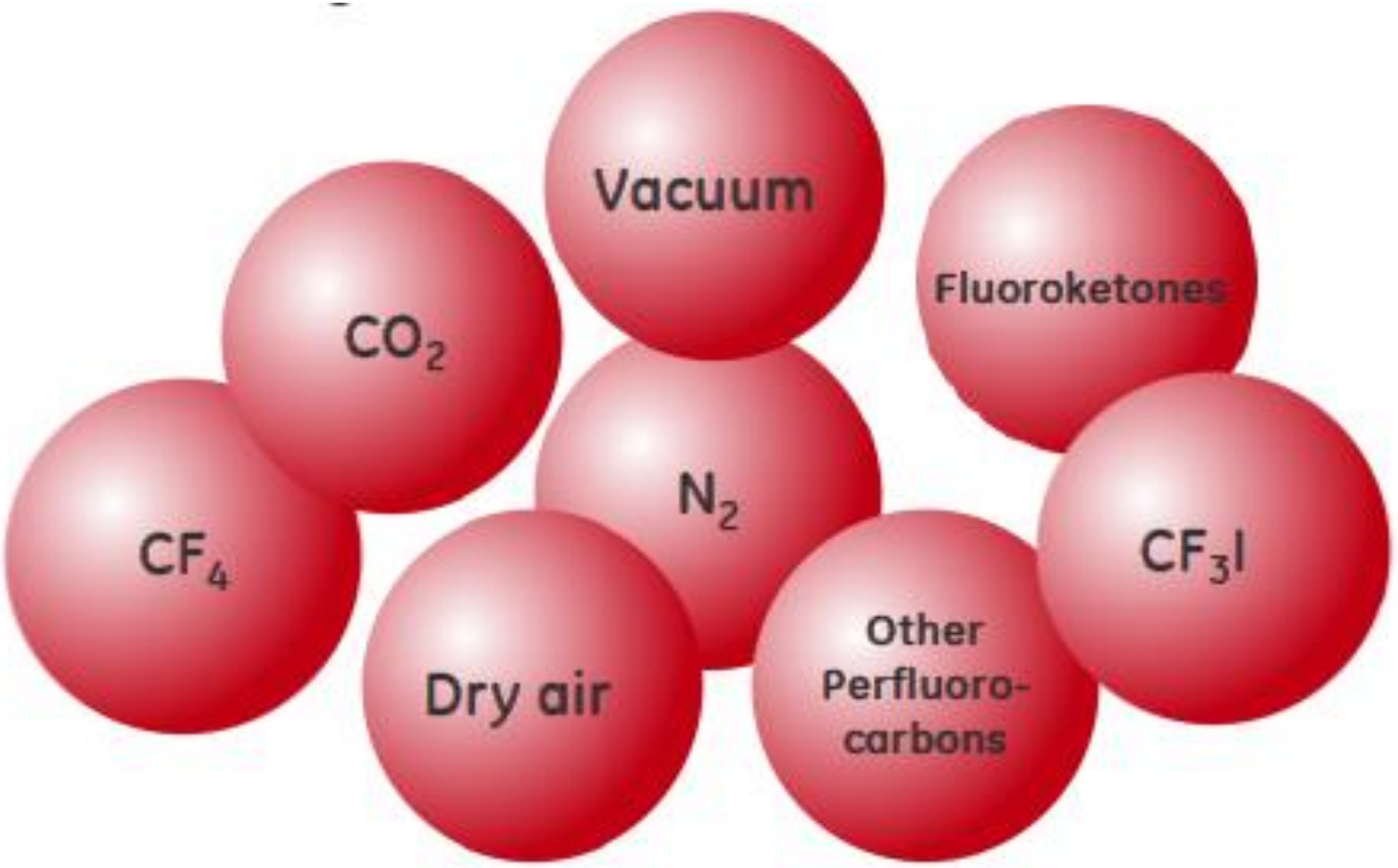






* Slow progression scenario used

Things that are not SF6



Requirements for non-SF6 solution

Environment

Low Global Warming Potential

- ≥ 95% reduction vs pure SF6
- No ozone depletion
- Environmentally sustainable

Performance

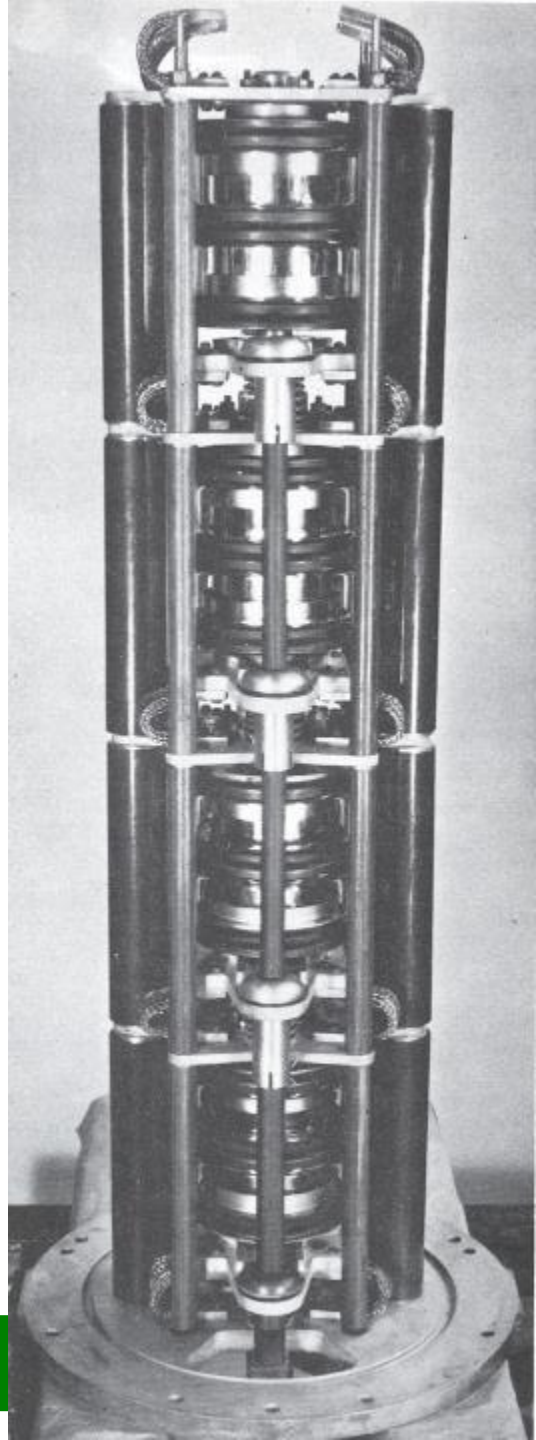
- To be used for dielectric insulation and disconnecting function
- To be used for arc switching function (optional)
- Dielectric strength ≥ to air, nitrogen or CO2 and as close as possible to pure SF6 at usual filling pressures for HV operating temperature according to standard -25°C (GIS), -30°C (others)

Safety

- Low toxicity (similar SF6),
- Non flammable
- Compatible with usual materials of HV equipment

SF6 alternatives

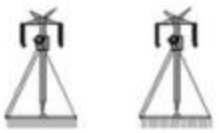
Financial incentive of ~£550 per kg lost or retained against target



Amenity

OHL design

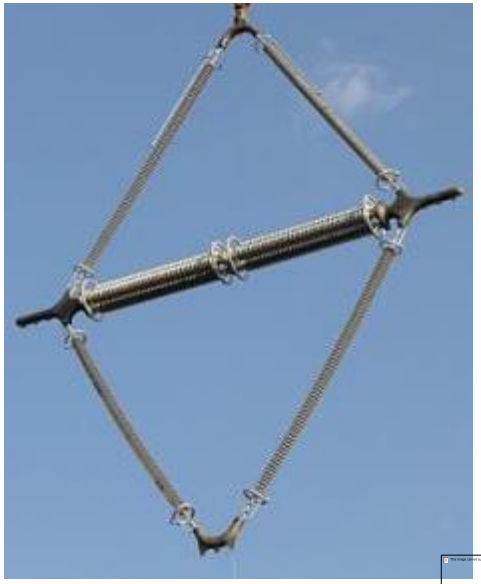
- Compact and high capacity overhead lines in the existing corridors.
- Hybrid AC & DC lines
- AC to DC conversion
- New conductors, insulators etc

	765 kV AC	500 kV DC	800 kV DC
Number of lines:			
Right of way (meter)	~ 240	~ 110	~ 90

Pylon design competition

- Winning entry: T-pylon
- We want to offer choice of tower types (including T-pylon) to local communities
- Working with designers on challenges:
  - Construction and safety
  - Reliability and maintenance
  - Need for angle tower

T-pylon design & development

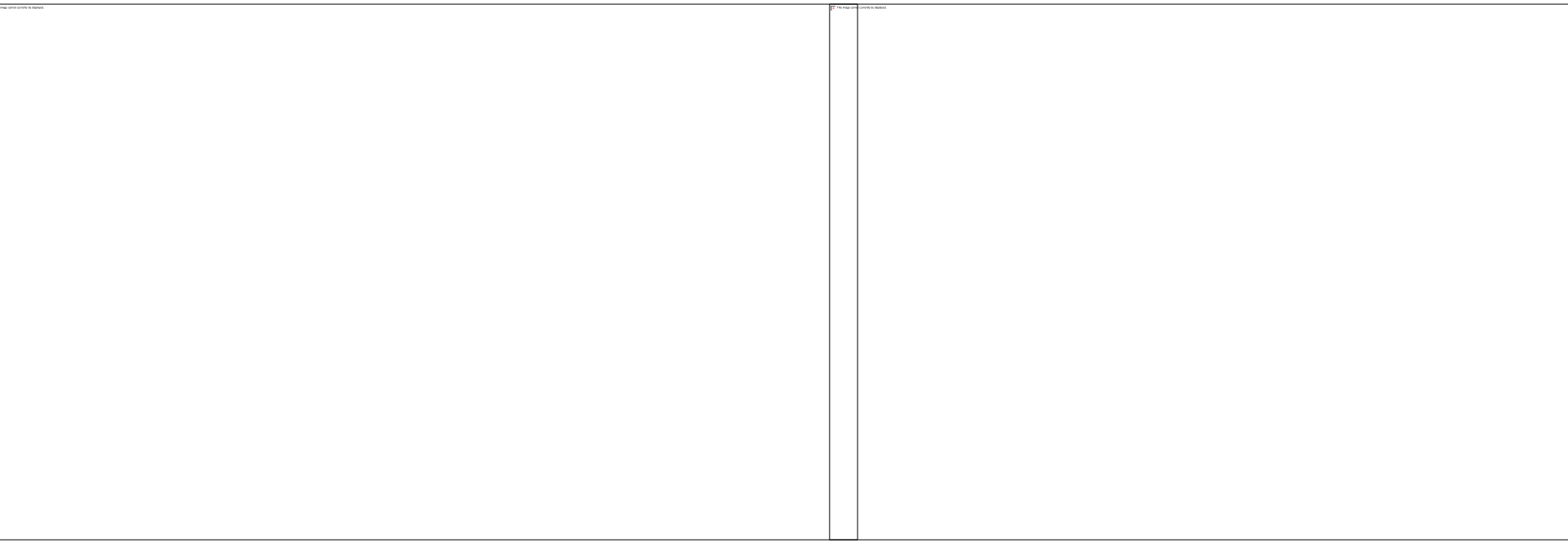


Just put it underground……

Sophisticated Asset Management

Asset Management

- **Asset management** is the coordinated activity of an organization to realize **value** from assets
- Right action, right place, right time

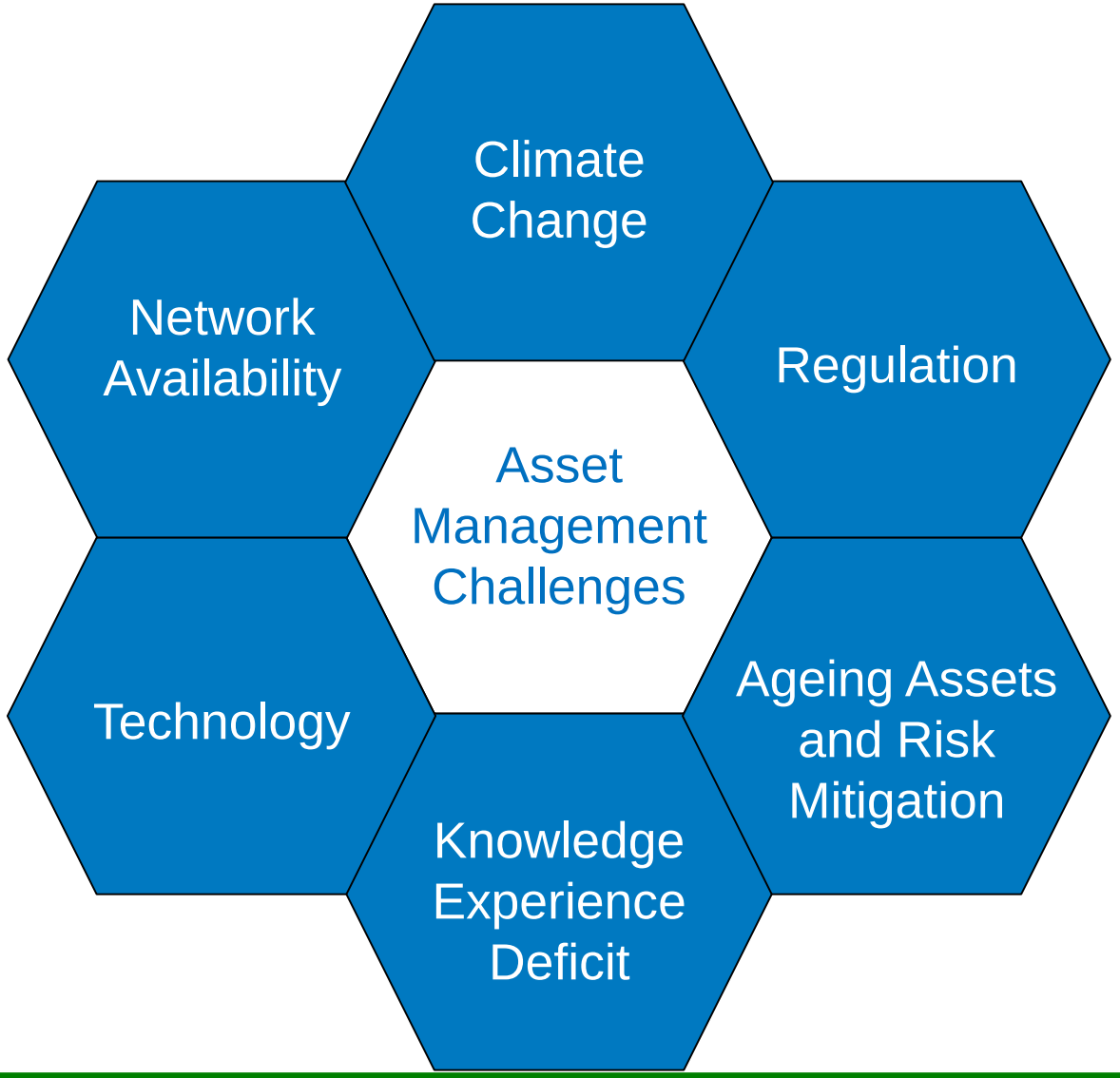


Asset Management Maturity Model

'Reactive based' (e.g. repair/replace on fail	'Interval based' (e.g. maintain at a set interval, replace at asset life)	'Condition based' (e.g. maintain/replace based on condition)	'Risk & Criticality based' (e.g. maintain/replace assets with the highest risk and greatest importance)

Increasing maturity of asset management

Some Challenges



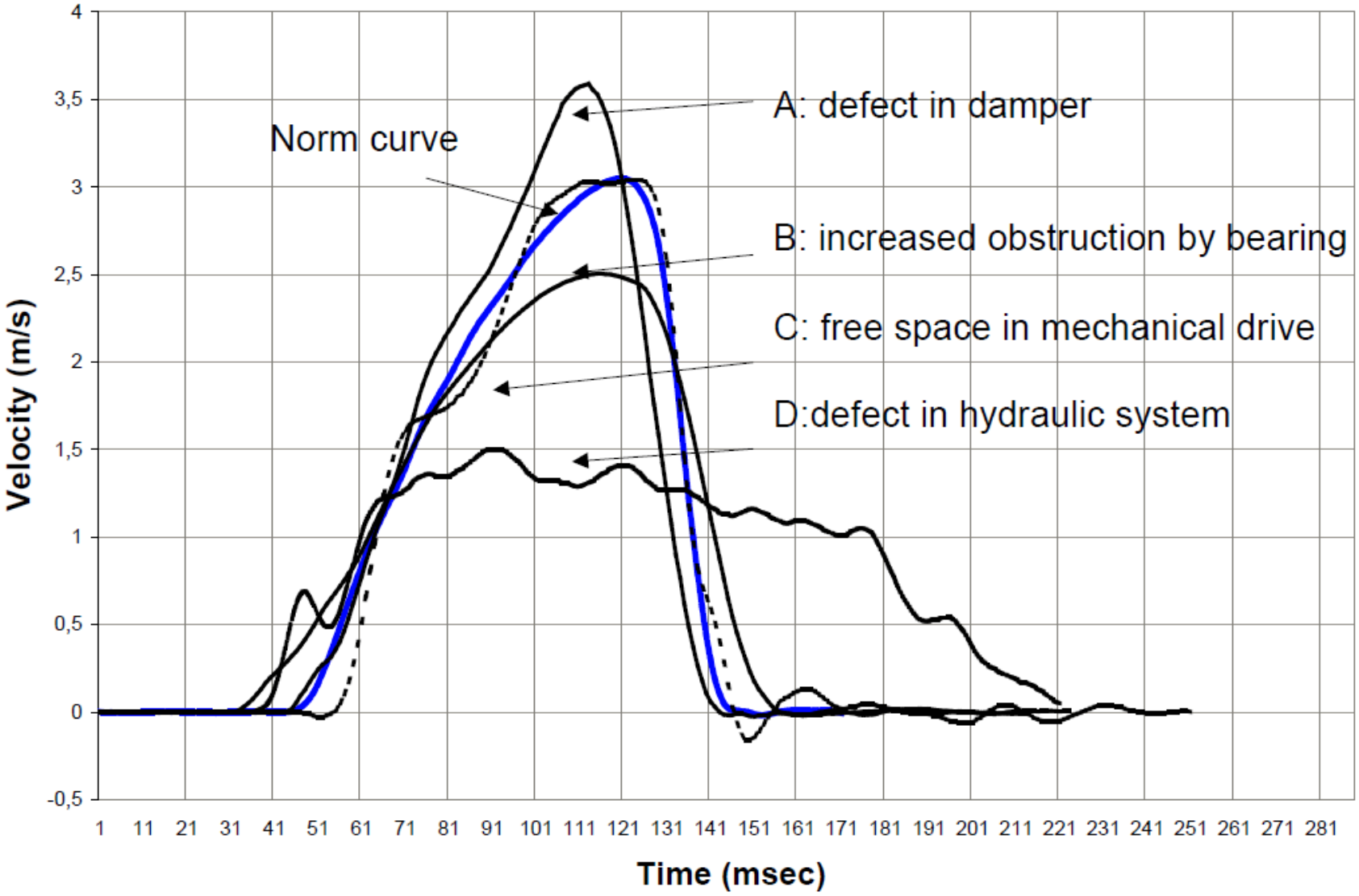
My Holidays

Traditional solutions

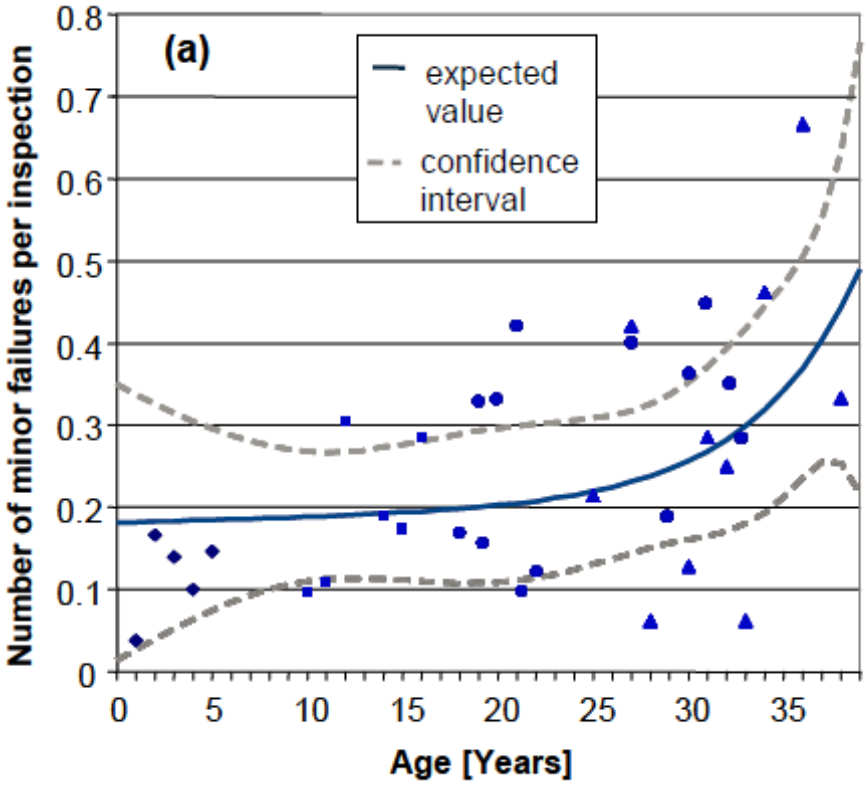
Diagnostics, monitoring, assessment

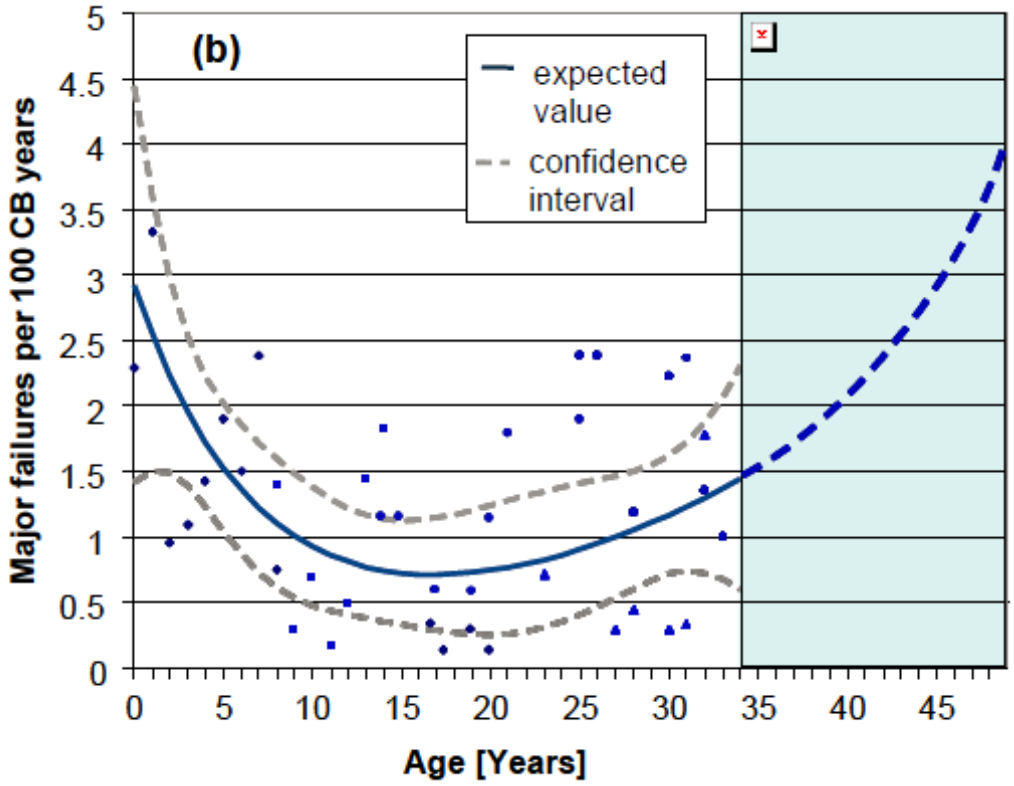
- Enable prediction of the time to intervene and give guidance on intervention required
- Tailored to the asset, material or application
- Useful & usable information
- Timely indications to permit planning
- Integration into business processes
- Cost effective for both small & large fleets
- Informed by historical data, live operational state, R&D, known design issues . . . . . .etc

Interpretation & application



Predictive techniques



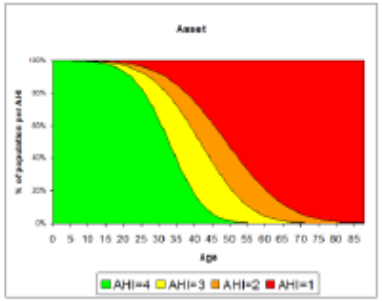


Test No: 060303-5029

Voltage: 237 kV peak
Current: 41,5 kA rms
Arc duration: 19,6 ms.

Camera speed: 25/1000 fr/sec.

Asset Risk



The Asset Health Index (AHI) is a representation of the relative health of an asset.

Environmental

Safety

System

The cost of recovery is the estimated cost of re-energising the circuit after a failure event. It varies from asset to asset and is used to compare between them.

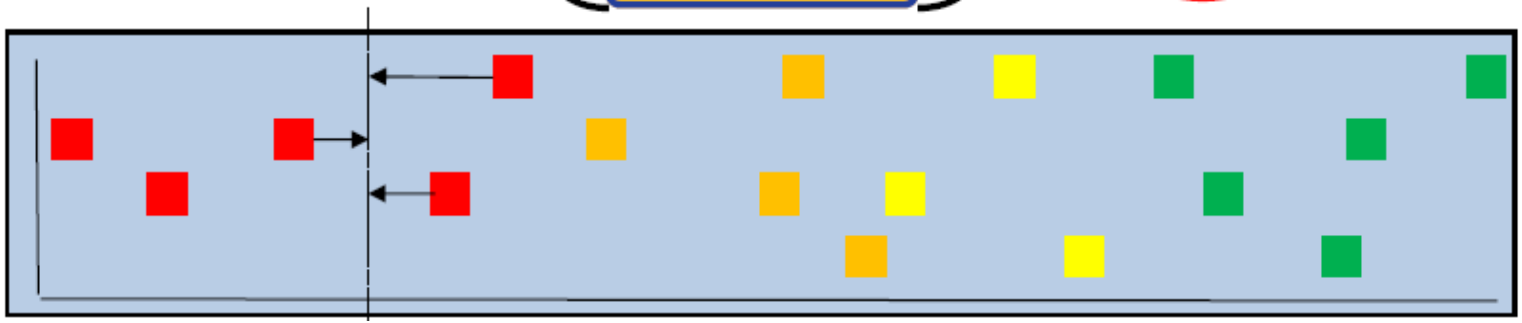
AHI

Criticality

Cost of Recovery

AHI x { Criticality + Cost of Recovery } = Risk (£)

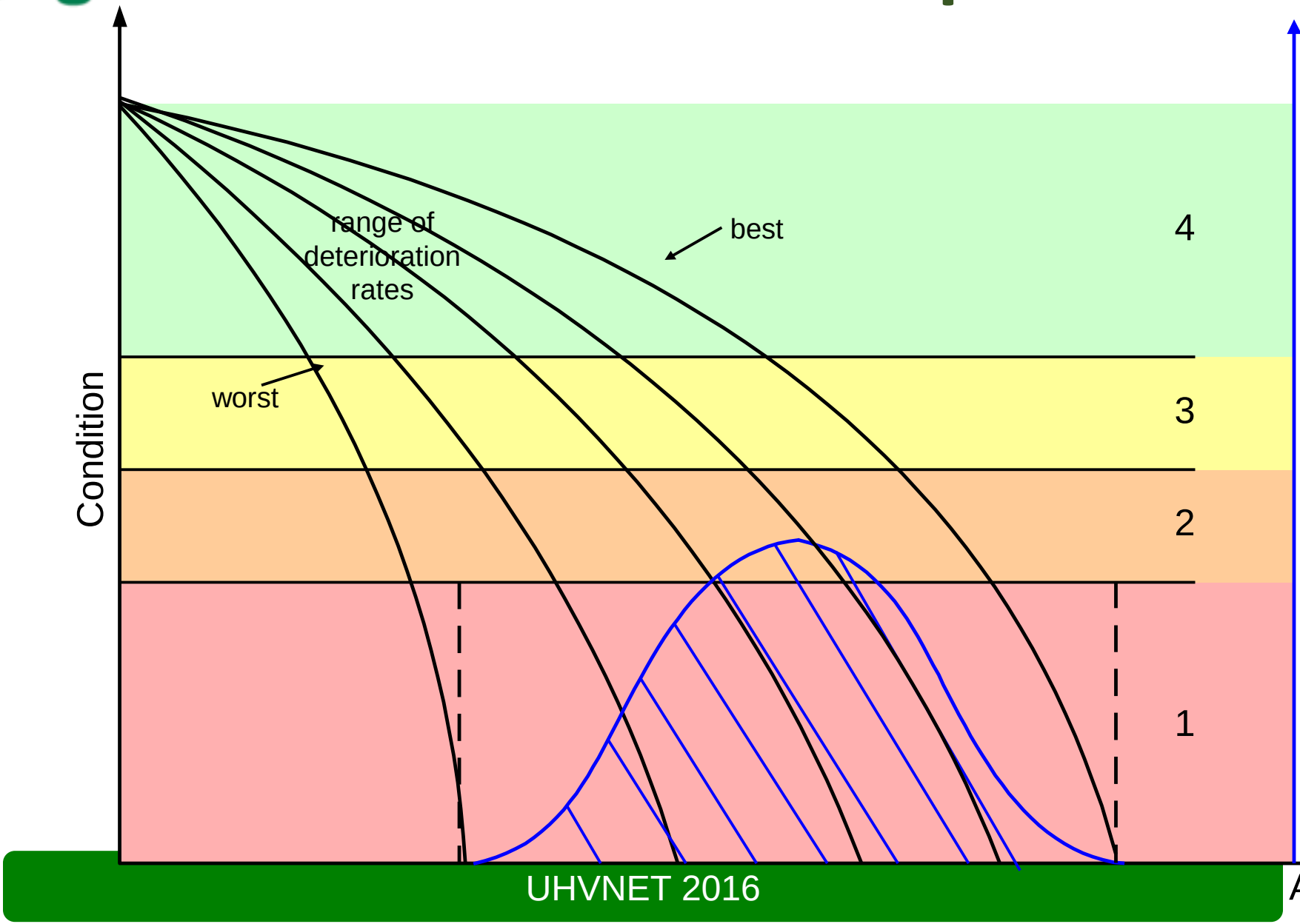
£



Asset Health Index

- Lead assets: OHL (conductor & fittings), transformers, cables, circuit breakers, reactors
- Generic life limiting factors for asset replacement
  - Condition – based on latest view given condition assessment/other data for individual unit or family
  - Family design weaknesses
  - Compliance with Legislation
  - Health and Safety performance
  - Equipment performance identified as inadequate in a system incident or formal investigation
  - Reduced equipment capability (condition affects capability)
  - Obsolescence
  - Refurbishment isn't an option or has not been undertaken

Asset Health of a Population



Criticality

- **System Criticality**
  - Impact of transmission system not delivering services
  - Developed in conjunction with GB System Operator
- **Safety and Environmental Criticality**
  - Consequence of failure or unreliability
  - Risk of direct harm to public/personnel as a result of failure
  - Environmental impact of asset unreliability or failure taking into account the sensitivity of the geographical area local to the asset.
  - Asset (location) specific
  - Derived where there is considered to be a material impact of asset failure/unreliability

Prioritisation

Higher Criticality

Worse Condition

	Criticality			
AHI	Very High	High	Medium	Low
1	0-2	0-2	2-5	2-5
High category 2	0-2	2-5	5-10	5-10
Medium/Low category 2	5-10	5-10	5-10	10+
3	10+	10+	10+	10+
4	10+	10+	10+	10+

Getting it wrong


SUNDON

Standardisation

Standardisation

- Value to Utilities and Manufacturers
- UHV AC
  - Good co-operation between IEC & CIGRE
- HVDC
- Testing (confidence in performance, electrical mechanical, environmental . . . . .)
- Compatibility
- Interoperability
- Risk of limiting innovation

IEC Technical Committee (HVAC/HVDC)		2014	————>2020	————>2030
TC8 (Systems aspects for electrical energy supply)	AC	The adoption of long distance and large capacity transmission system	UHV transmission system expands Development of UHV system standards	Widespread UHV transmission systems (cross-country) Intersection for DC-Grids
	DC	LCC-HVDC => High power capability VSC-HVDC=>Lower power capability	VSC-HVDC Cap Increase (80% HVDC:VSC), Standard Voltage HVDC Transmission => DC Grid + DC breaker	Integration of DC grids & AC grids Interoperability of DC grids Increase of Multi-terminal HVDC and DC grids->E-highway
TC13 (Electrical energy measurement, tariff- and load control)	AC	IEC 62056 DLMS/COSEM suite => New smart metering applications and security requirements	IEC 62052/62053 => Adaptation to new electronic metering technologies; adapting to changing EMC environment. IEC 62056 DLMS/COSEM suite => harmonizing application model and communication profiles for smart electricity, gas, water, heat and consider advanced end-to-end data security	Voltage and current transformer operated meters using new measuring instrument transformer technologies. Integration of smart meters into M2M and "Internet of Things" environment.
	DC	Extension of scope for DC metering. NWIP on DC metering accepted (13/1510/RVN)	Modeling of DC metering related applications	-
TC14 (Power transformers)	AC	On-site assemble EHV & UHV transformers Environmental & fire safety transformers	Wide spread of on-site assemble EHV & UHV transformers Wide spread of Environmental & fire safety transformers	Operation transformer equipped semi-conductor type OLTC Operation Superconductivity Current Limiter & TR
	DC	UHV converter TR	On-shore /off on-site assemble UHV converter TR	Wide spread of On-shore /off on-site assemble UHV converter TR
SC17A/SC17C (SWITCHGEAR & CONTROLGEAR)	AC	Medium voltage switchgear: compactness and withstand to harsh climatic conditions including flooding are more and more required in public distribution., Short Circuit current increase up to 80kA	Medium voltage : VCB share increase High voltage: SF6 GCB continues	-
	DC	R&D of DC-circuit breaker started	Application of DC-grid circuit breaker in multi-terminal HVDC grid or DC grid	Wide spread of DC-breaker in DC grid and multi-terminal HVDC system
TC20 (Electric cables)	AC	Up to 500kV cable	Up to 800kV cable	Up to 1200kV cable
	DC	HVDC system (On shore off shore)MI cable mainly applied ±320kV -> ±400kV	HVDC system (On shore off shore)MI cable -> XLPE Cable Max rating : ±500kV-2000A Cable	Wide spread of XLPE Cable Max rating : ±800kV-2000A Cable
TC22,SC22F (Power electronic systems and equipment)	DC		Hybrid DC-CB and other fault current interrupting means Interface of a.c. systems and energy storage systems	VSC HVDC based city in feed systems
TC28	AC			
	DC	HVDC insulation coordination	Preparing the standardization of DC equipment rated voltage and current , testing LI, SW, DC voltage	Standardization of DC equipment rated voltage and current , testing LI, SW, DC voltage
TC36 (Insulators)	AC	Composite Insulator application Pollution criteria review	Wide spread of Composite Insulator application	
	DC			
TC37 (Surge arresters)	AC		Integration of MOSA with distribution equipment	Field grading with micro varistors Composite varistors
	DC	Preparing for DC Arrester standard	High field MO resistors for bridge arresters	Wide spread of LSA for DC transmission lines Charge release from insulators with micro varistors

IEC Technical Committee (HVAC/HVDC)		2014	——————>2020	——————>2030
TC38 (Instrument transformers)	AC	Digital VT/CT Fiber optics VT/CT	Wide spread Digital VT/CT	Wide spread Digital VT/CT
	DC	Optical DC CT Kraemer type CT	Wide spread of Optical DC CT	
TC57 (Power Systems Management and Associated Information Exchange)	AC & DC	Overall architecture for information exchanges for electricity grids, and related standards (control, protection, asset management, DA, EMS, market, cyber security, etc.)	Architecture exchange extension to: • Cross cutting applications (Demand / response; Voltage control…) • Mesh grids (HVDC & AC) • Interfaces with Home & Buildings information and control systems • 62351 for cyber security end to end solutions to TC57 standards.	-
	DC specific	CIM (common information model) for HVDC links	CIM for HVDC multi-links (asset management, operation, control) 61850 for HVDC station control, operation & protection	-
TC90 (Superconductivity)	AC		66kV-275kV cable, current limiter? Transformer?	Expand of AC transmission system, 500kV cable?
	DC	DC-transmission system	Expand of DC-transmission system	
TC95 (Measuring relays and protection equipment)	AC	IEC 61850, Local Area Protection ->Wide Area Monitoring System	Wide spread of Wide Area Monitoring System / Wide Area Monitoring Protection and control / New functions for loss of mains detection	Wide spread of Wide Area Monitoring Protection and control
	DC		Specific protection for DC lines	
TC115 (High Voltage Direct Current (HVDC) transmission for DC voltages above 100 kV)	DC	VSC-HVDC increase Max rating ±320kV ±800kV 7,200MW LCC HVDC power transmission systems ±320kV 800MW VSC HVDC power transmission systems	HVDC transmission system expands Max rating ±800kV Preparation for the HVDC system standards ±1100kV LCC HVDC power transmission systems DC power tapping	HVDC transmission system expands Max rating : ±1200kV Preparation for the HVDC system standards incl. DC-CB. DC grids