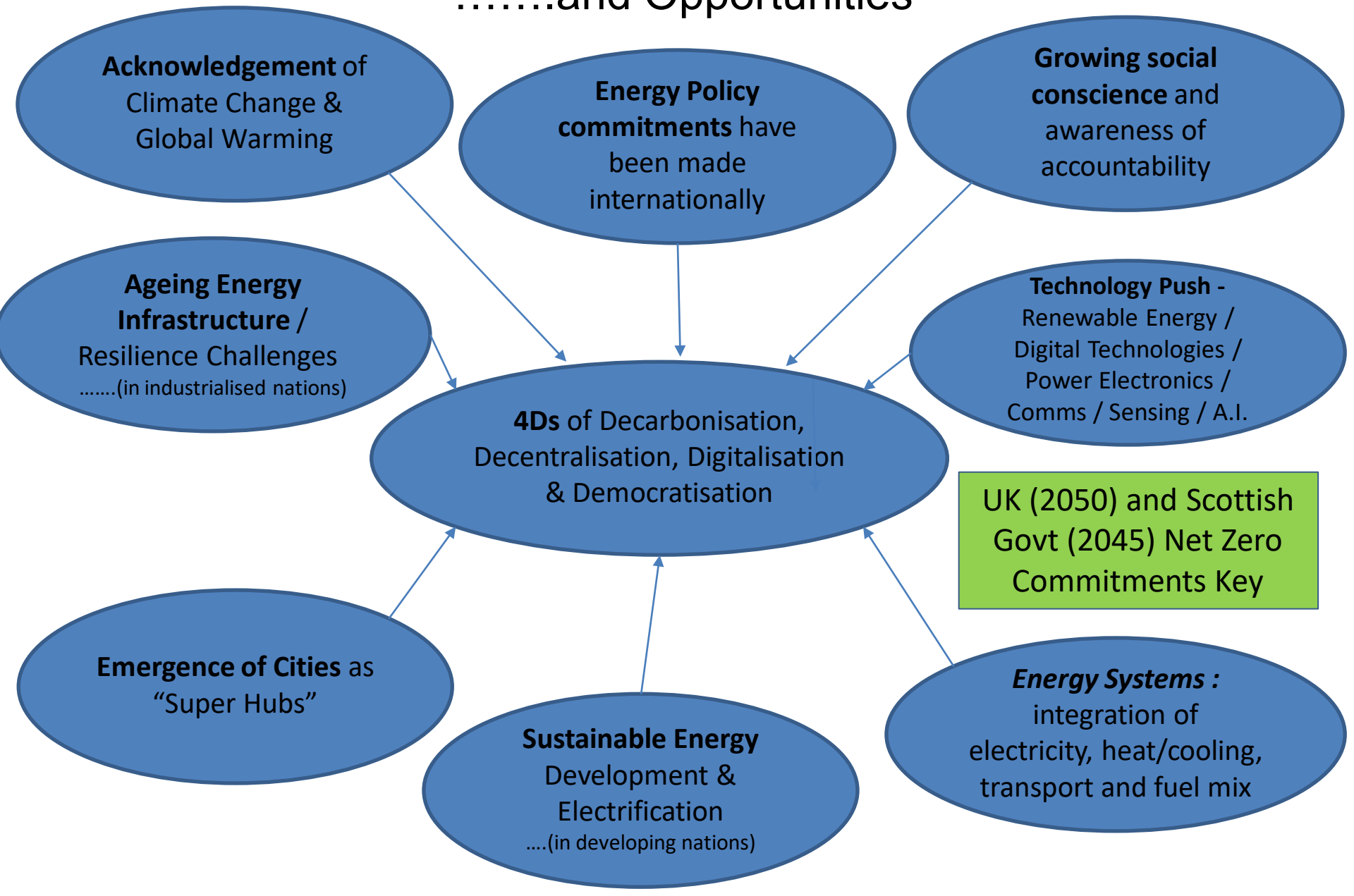
Energy Systems for the 21st Century

The 4Ds: decentralisation; decarbonisation; digitalisation; democratisation

Scottish Energy Forum
April 2020

Jim McDonald
Principal and Vice-Chancellor
University of Strathclyde

Convergence of Pressures, Commitments, Technologies …….and Opportunities



Committee on Climate Change

The Royal Society of Edinburgh

KNOWLEDGE MADE USEFUL

Committee on Climate Change

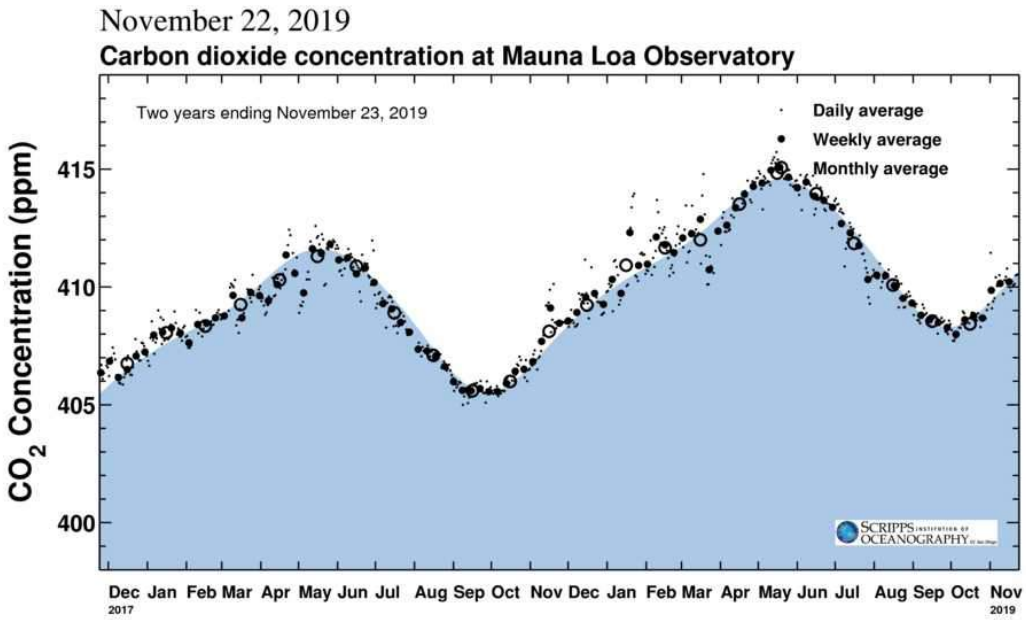
30 April 2020

Net Zero

Chris Stark
Committee on Climate Change

Global warming

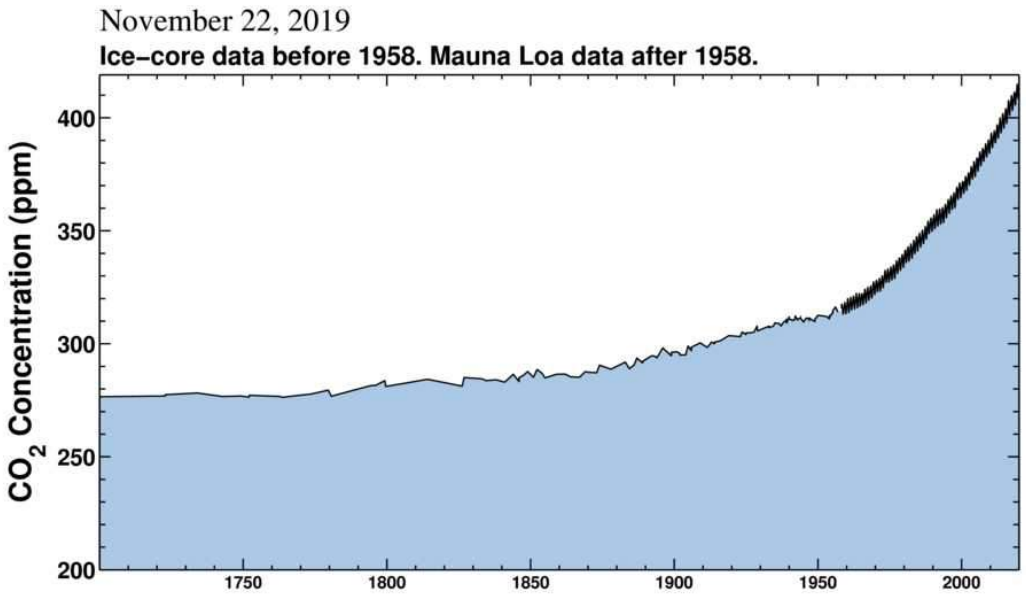
CO_2 Concentration – 2017 to 2019



Source: Scripps Institution of Oceonography

Global warming

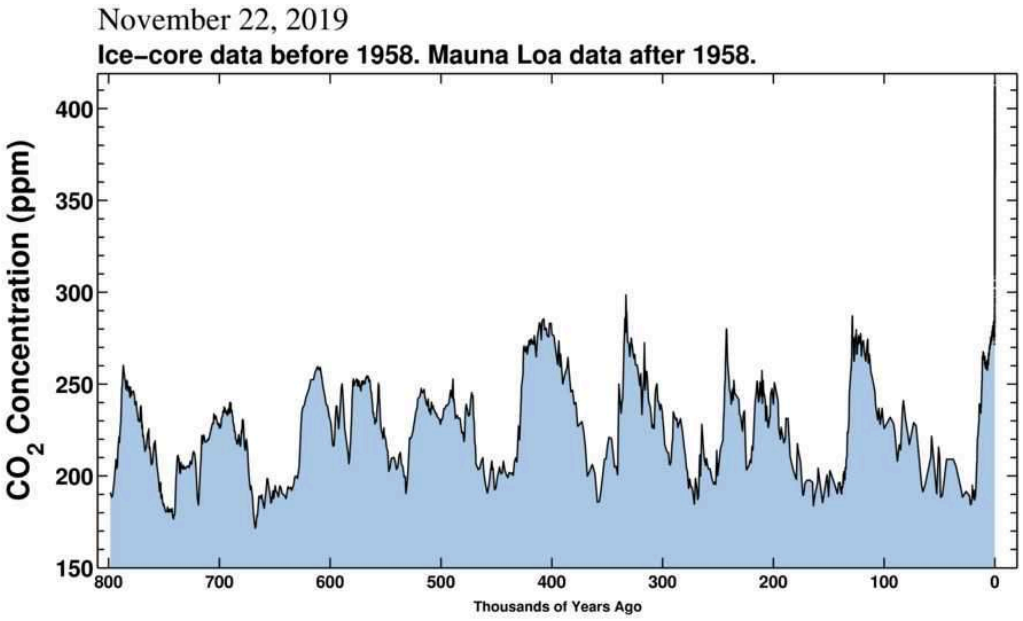
CO_2 Concentration – 1700 to Present



Source: Scripps Institution of Oceonography

Global warming

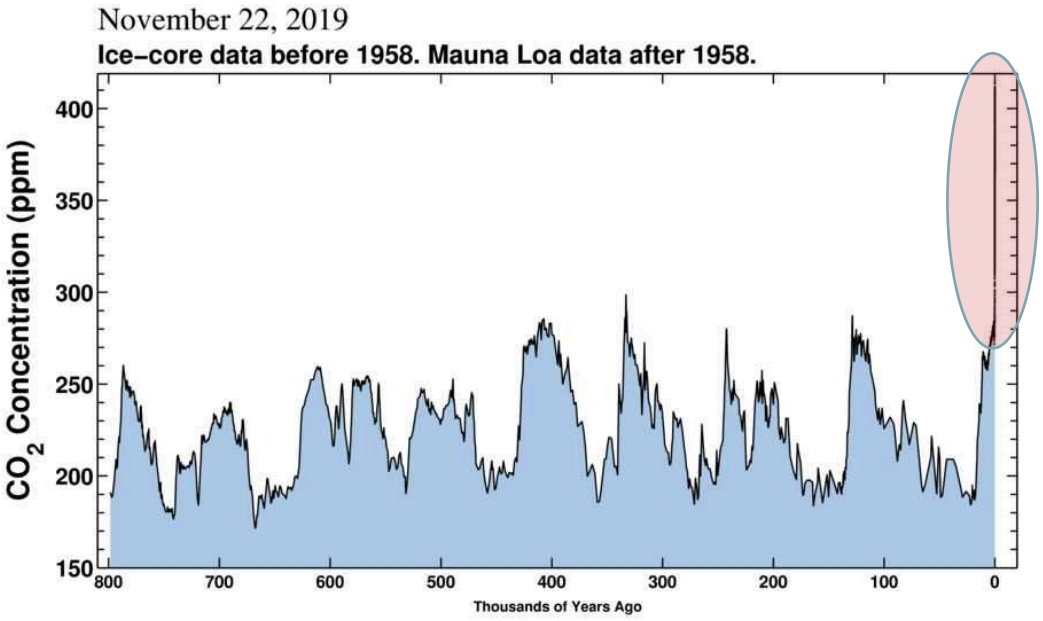
CO_2 Concentration – 800,000 years



Source: Scripps Institution of Oceonography

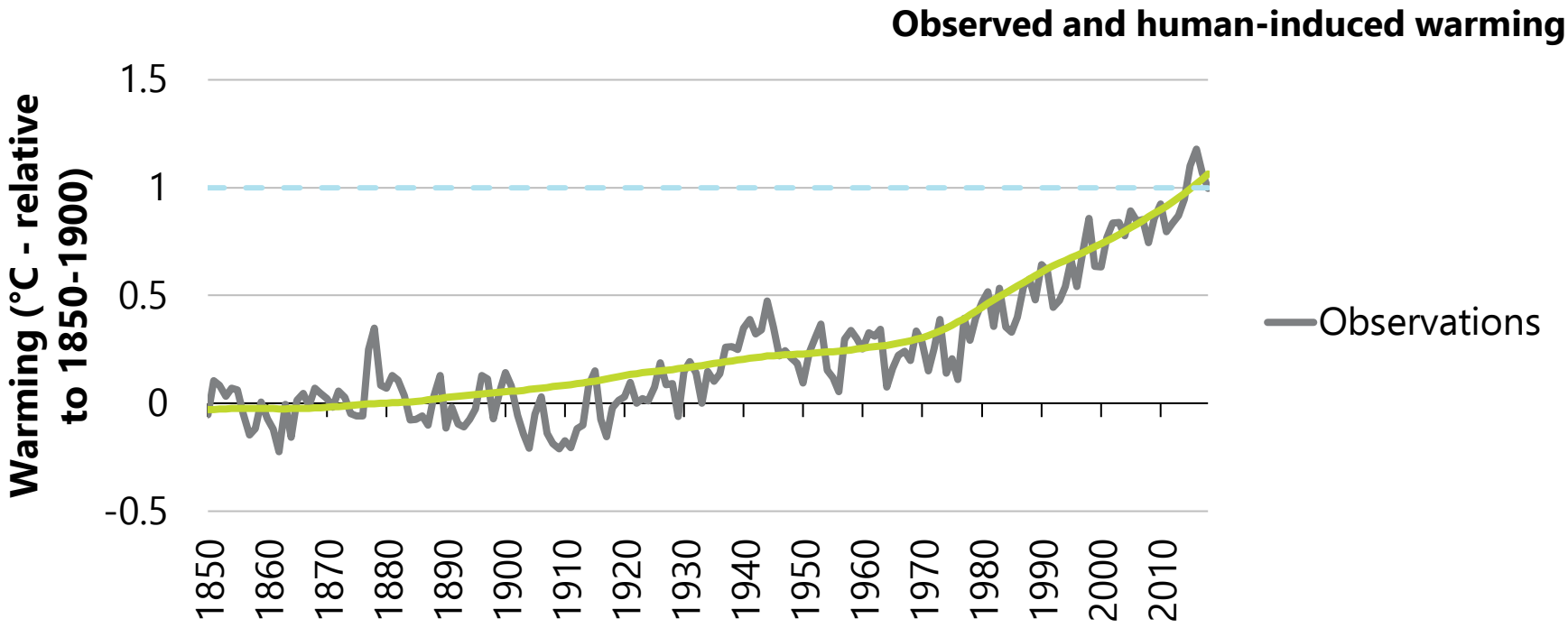
Global warming

CO_2 Concentration – 800,000 years



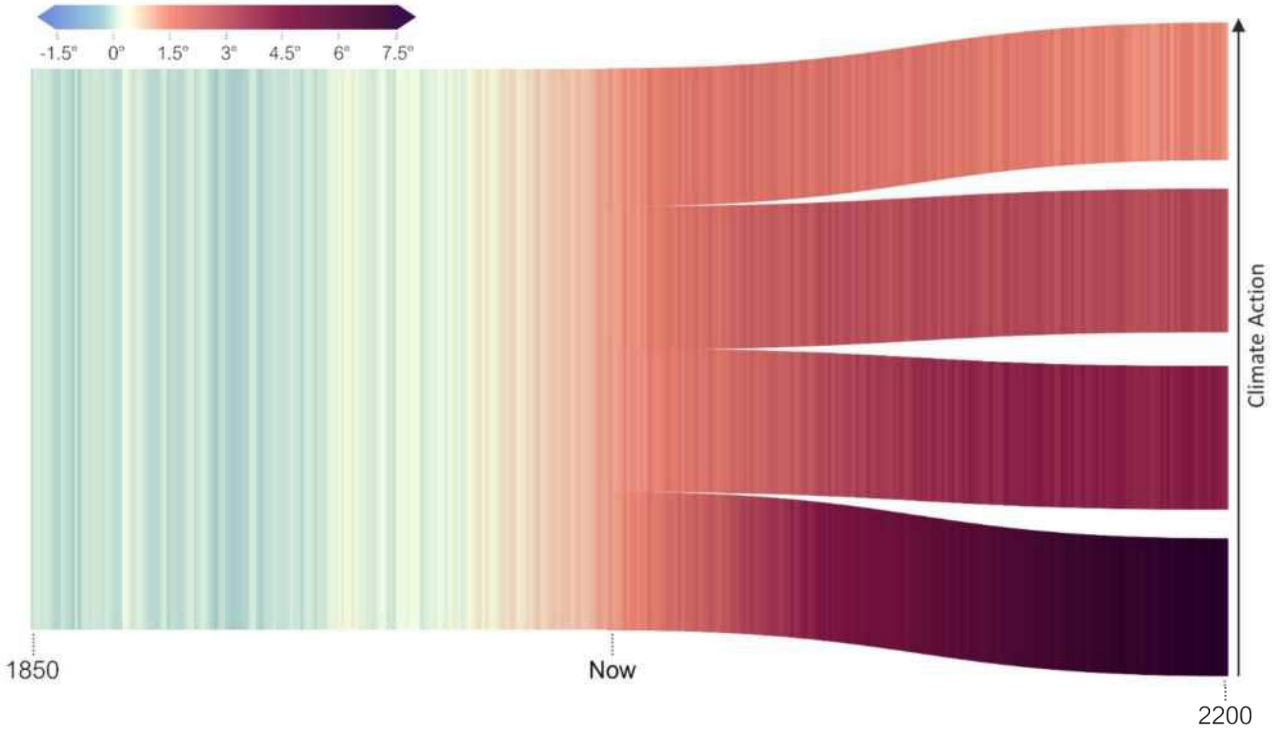
Source: Scripps Institution of Oceonography

Global warming



Source: HadCRUT4, NOAA, NASA and Cowtan & Way datasets; IPCC (2018) Chapter 1 - Framing and Context.

The climate choice



+1.9ºC in 2100/+1.4ºC by 2200
Emissions peak by 2029;
Negative emissions by 2080

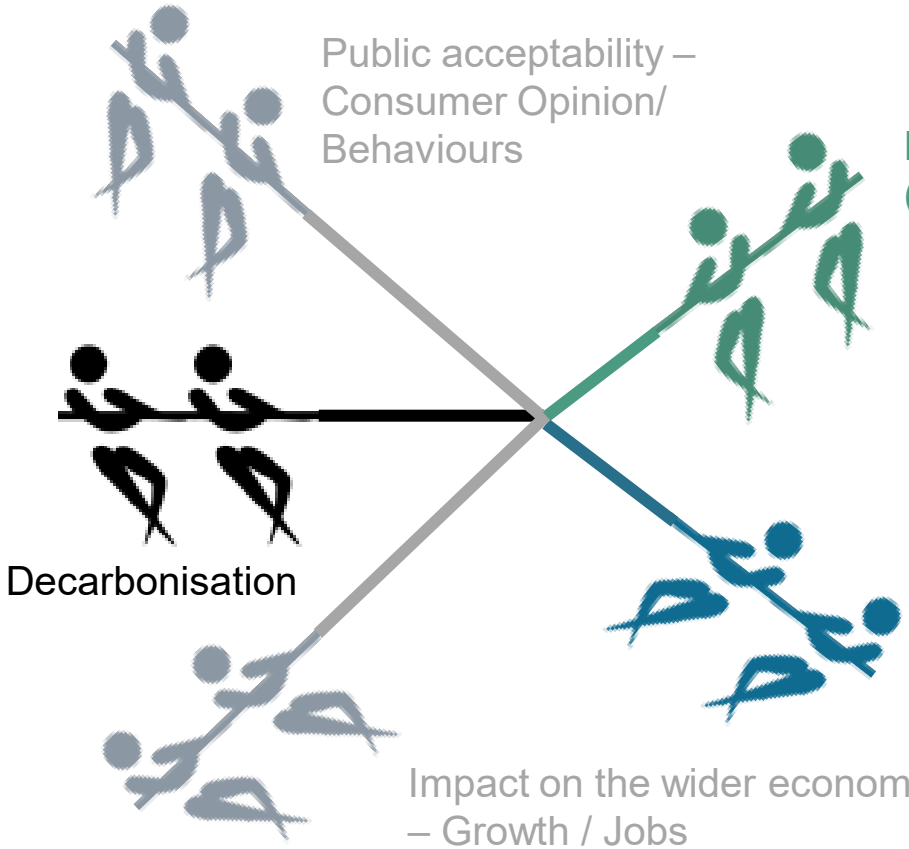
+2.7ºC in 2100/+2.8ºC by 2200
Emissions peak by 2049

+3.1ºC in 2100/+3.7ºC by 2200
Emissions peak by 2089

+4.8ºC in 2100/+7.8ºC by 2200
Emissions peak between 2100 - 2150

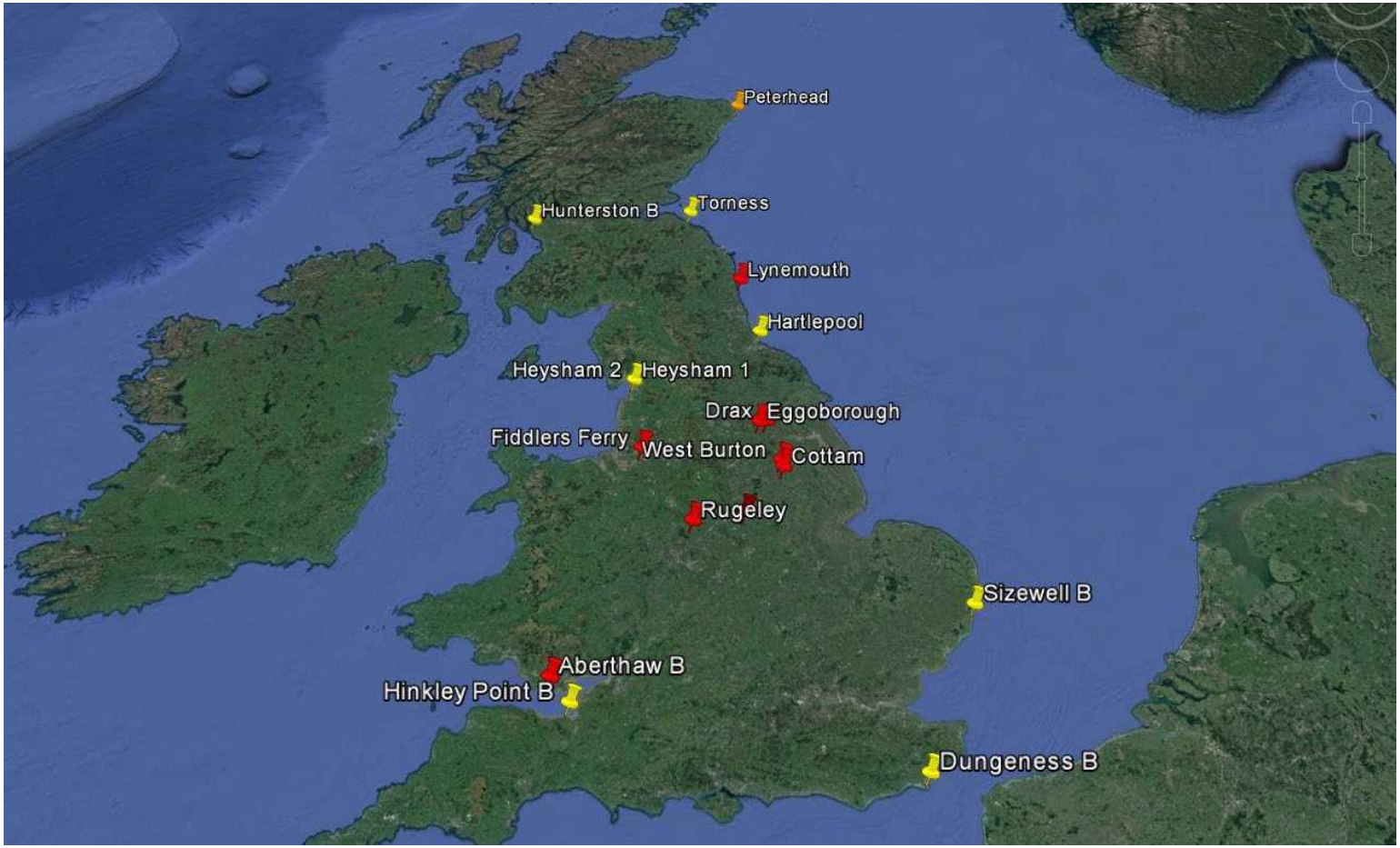
Source: Projections based on CMIP5 RCP scenarios, from warningstripes.com

Key Driver: The Energy Trilemma (and extensions….)



What are the options ?
What will they cost ?
Will they work ?

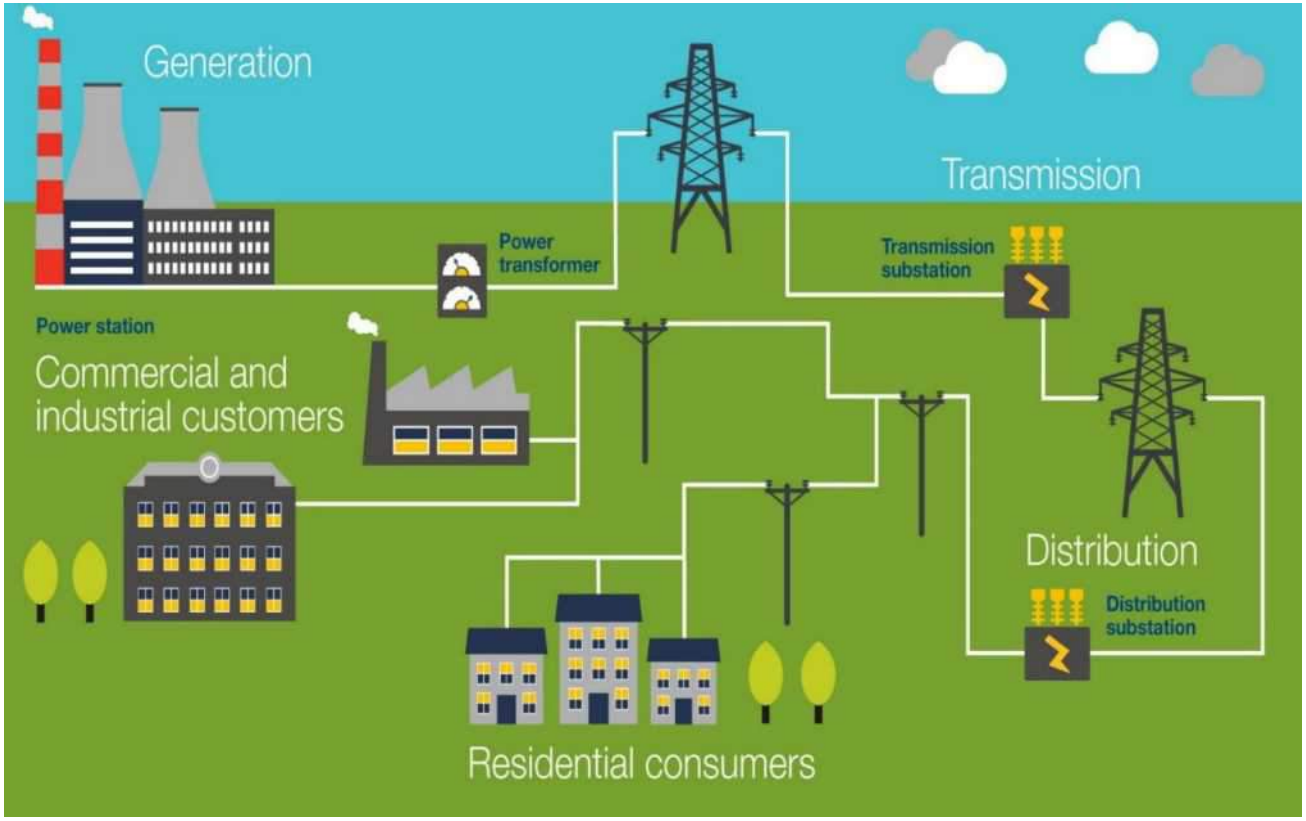
A UK perspective:
Current Coal / Major Gas & Nuclear Power Stations



Post 2025 Coal / Major Gas & Nuclear Power Stations?

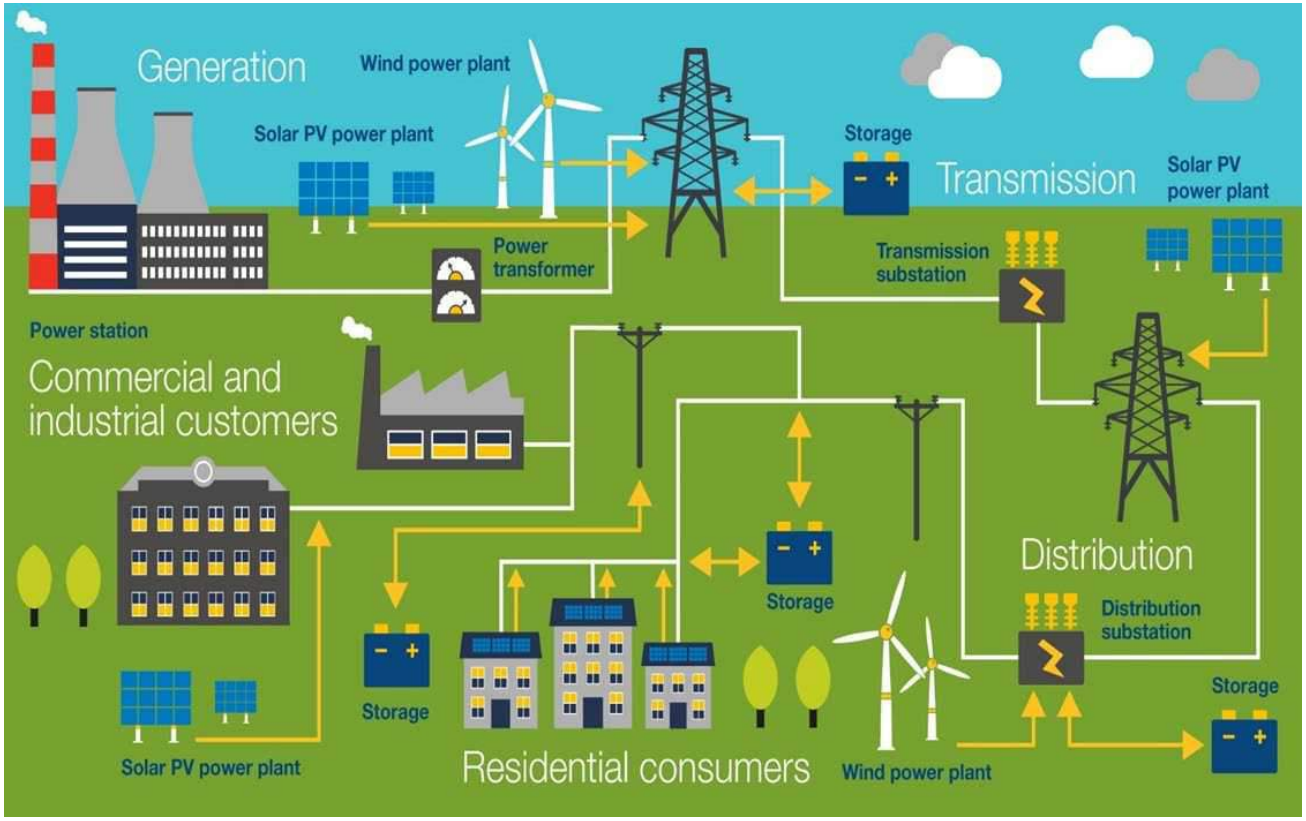
National Grid 2050 Future Energy Scenarios:

Traditional Power System



nationalgridESO

Future Power System



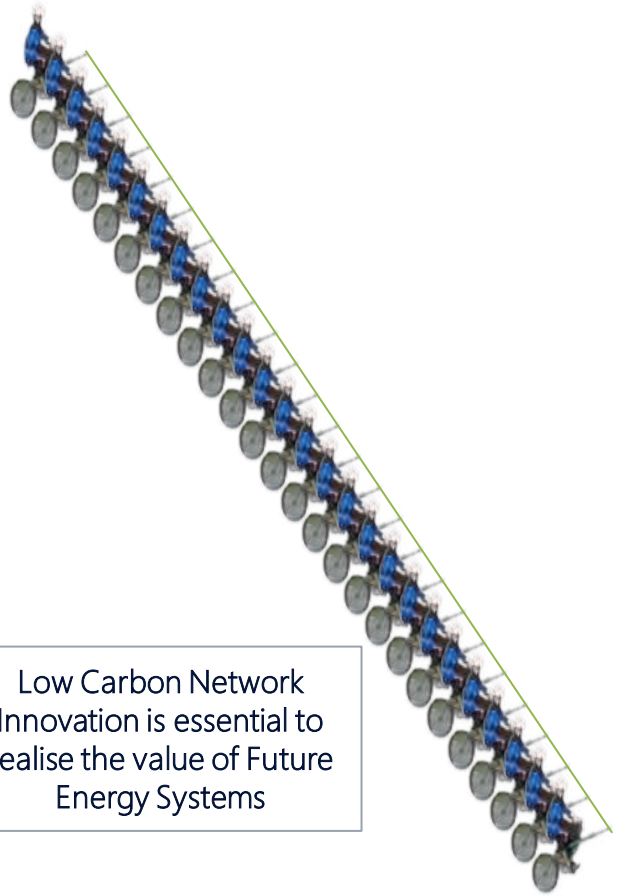
nationalgridESO

Grid composition analogy

2000

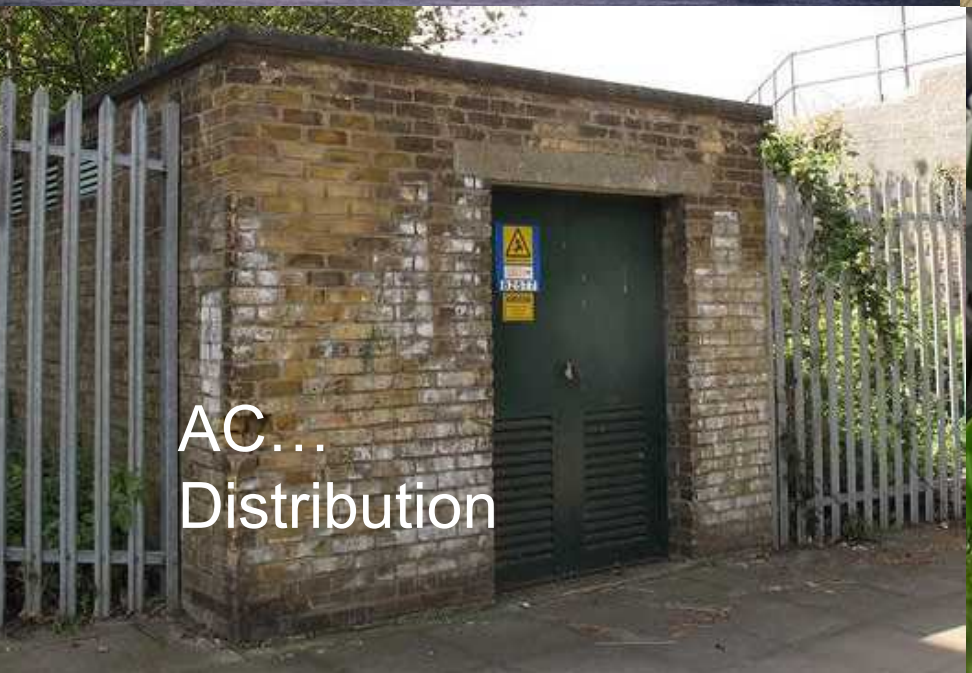
Today

2030



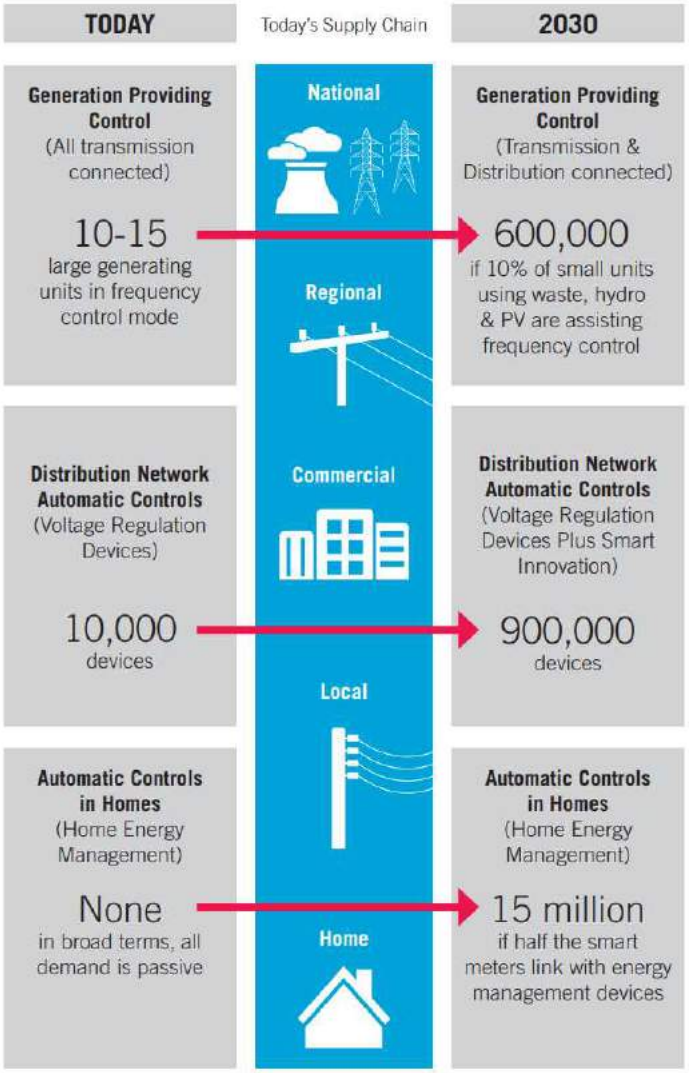
Low Carbon Network Innovation is essential to realise the value of Future Energy Systems

The Network will evolve…….



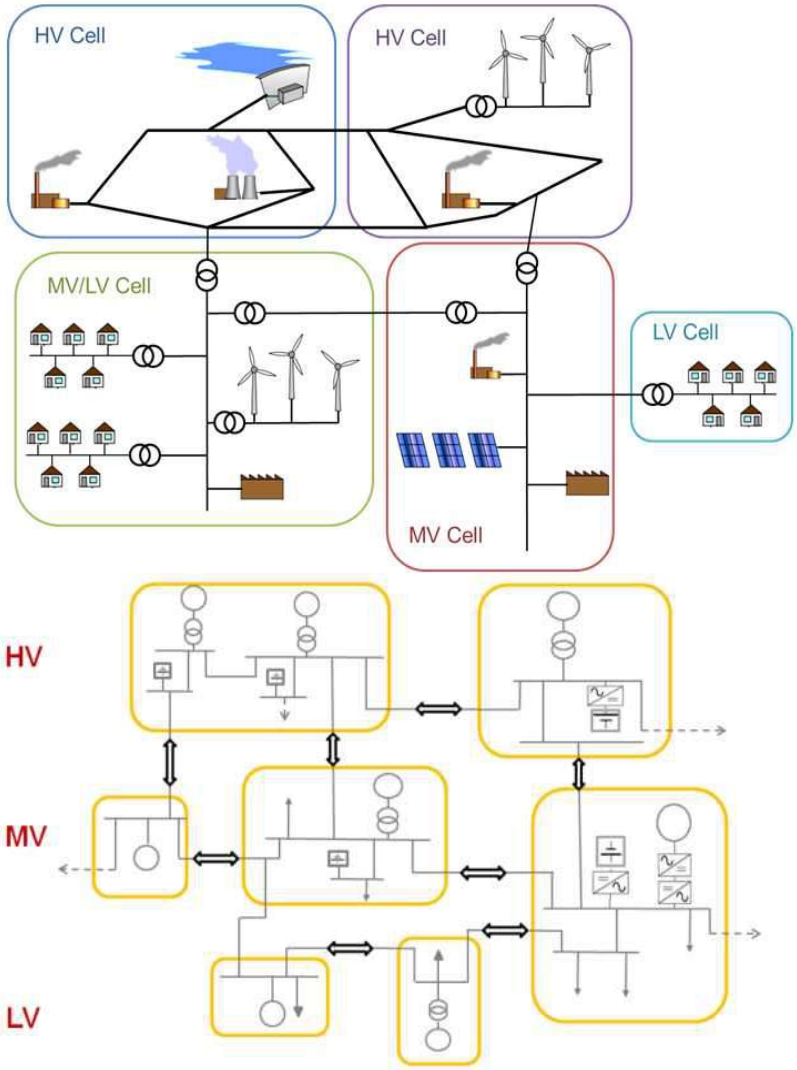
UK: growth in controllable resources (and complexity)

- Massive increase in:
  - Monitoring & Control data
  - Controllable units (generators, energy storage, etc)
- Needs breakthrough in comms, data and control infrastructure and security
- Opportunities for data analytics and machine learning applications
  - Distributed intelligence and automation

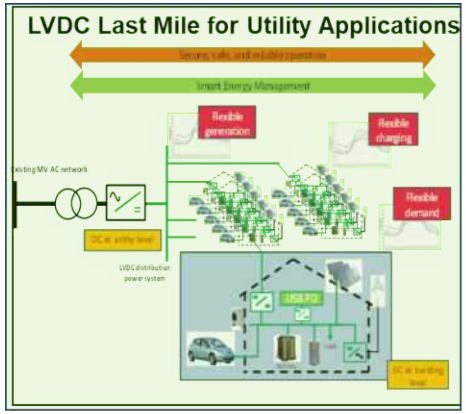


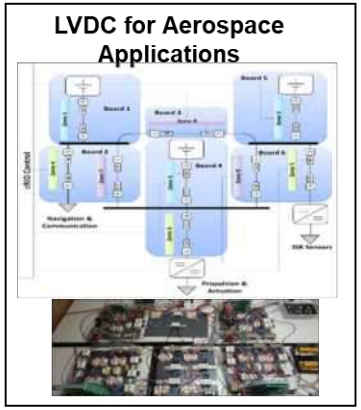
ELECTRA IRP: *"Web-of-Cells"* concept

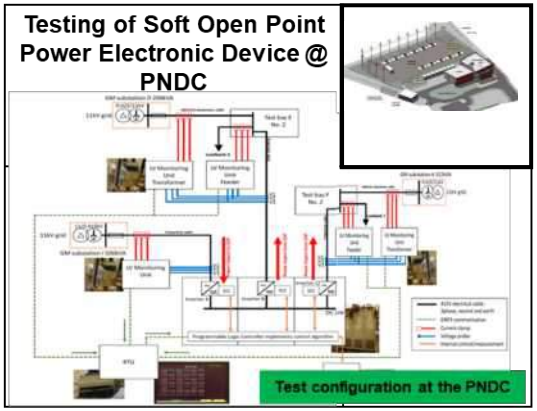
- "Divide and conquer"
  Split system into geographic "cells"
  - Each cell attempts to maintain forecast schedule of power exchanges
  - Each cell has a control room or Cell Operator
    - May be "virtual" – purely automated functionality
  - Each cell contributes to overall frequency control
- Communications practical over shorter distances
- Distributed Control and Automation ("smart grid")
- Voltage issues are relatively "local"
  - e.g., PV on 11 kV feeders will not affect 33 kV
- "Outer" control loops perform global balancing (or other optimisation)

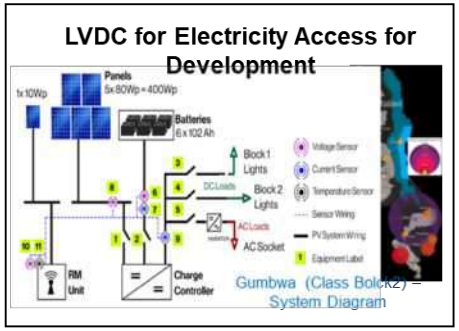


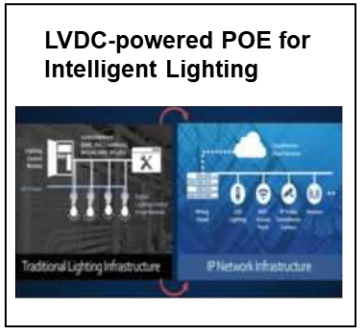
University of Strathclyde
LVDC in power distribution

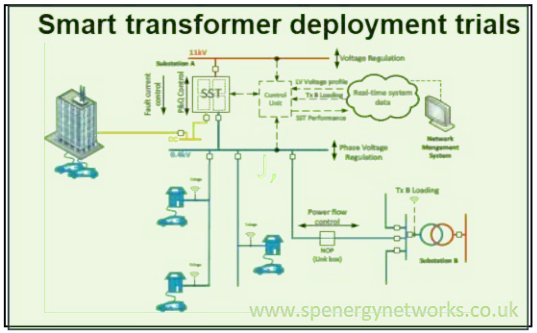












Professional contributions include:

- IEC SG4 LVDC Systems Committee and TC8/WG9
- IET Technical Committee 2.4 on LVDC power systems
- UK National Committee GEL/050 on LVDC
- Emerge Alliance

Distributed Network and Electrification Analogies:

Aero-electrical and Marine-electrical Systems

- **Technological and Strategic Convergence:**

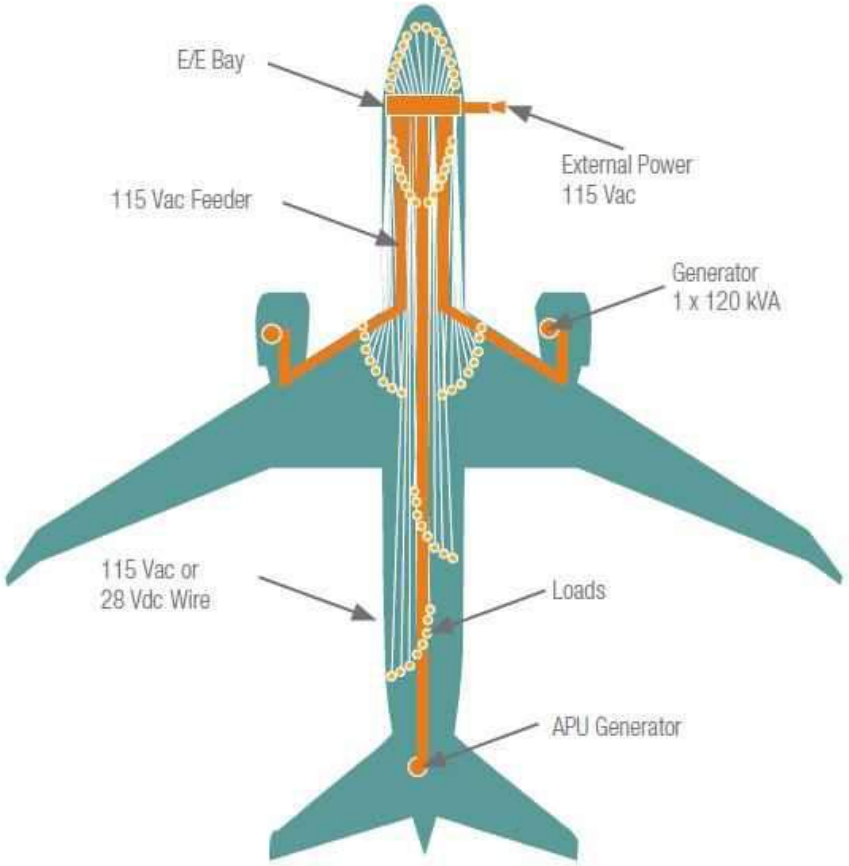
  Similar drivers apply for:

  - Distributed electrical energy systems
  - Decarbonisation and reduced environmental impact
  - Digitalisation – sensing, comms, data analytics, autonomy

Micro-grids in modern aircraft reducing cable usage by ~20 miles!

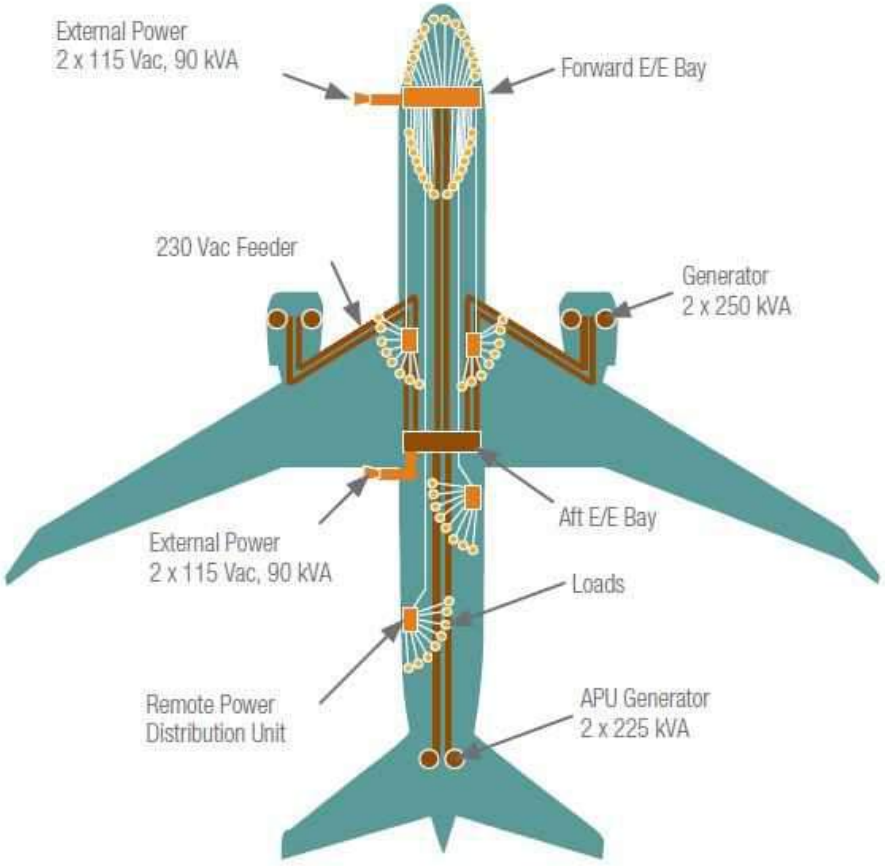
University of Strathclyde Engineering

TRADITIONAL



Centralized Distribution:
Circuit Breakers, Relays,
and Contactors

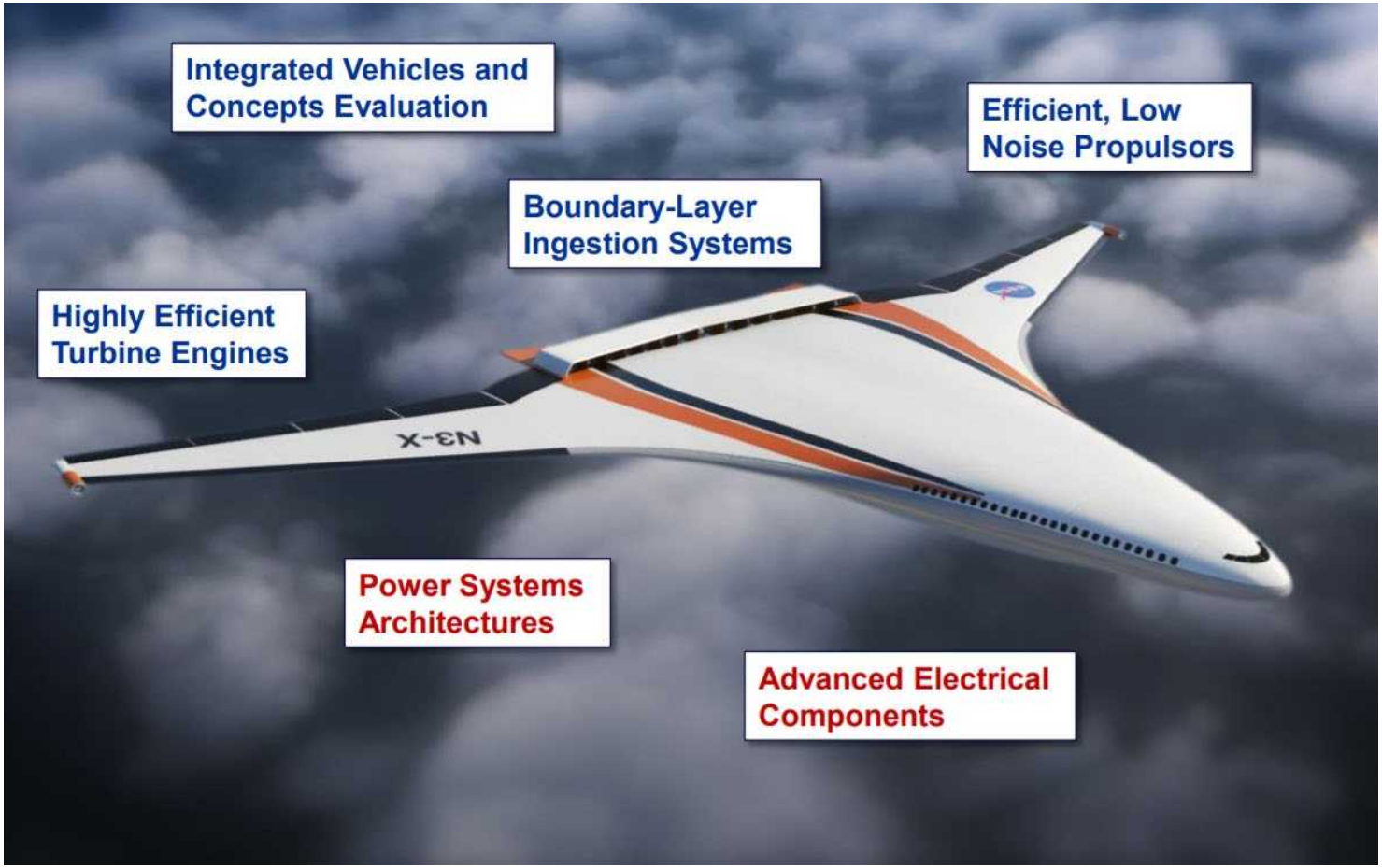
787



Remote Distribution:
Solid-State Power Controllers
and Contactors

https://www.boeing.com/commercial/aeromagazine/articles/qtr_4_07/AERO_Q407_article2.pdf

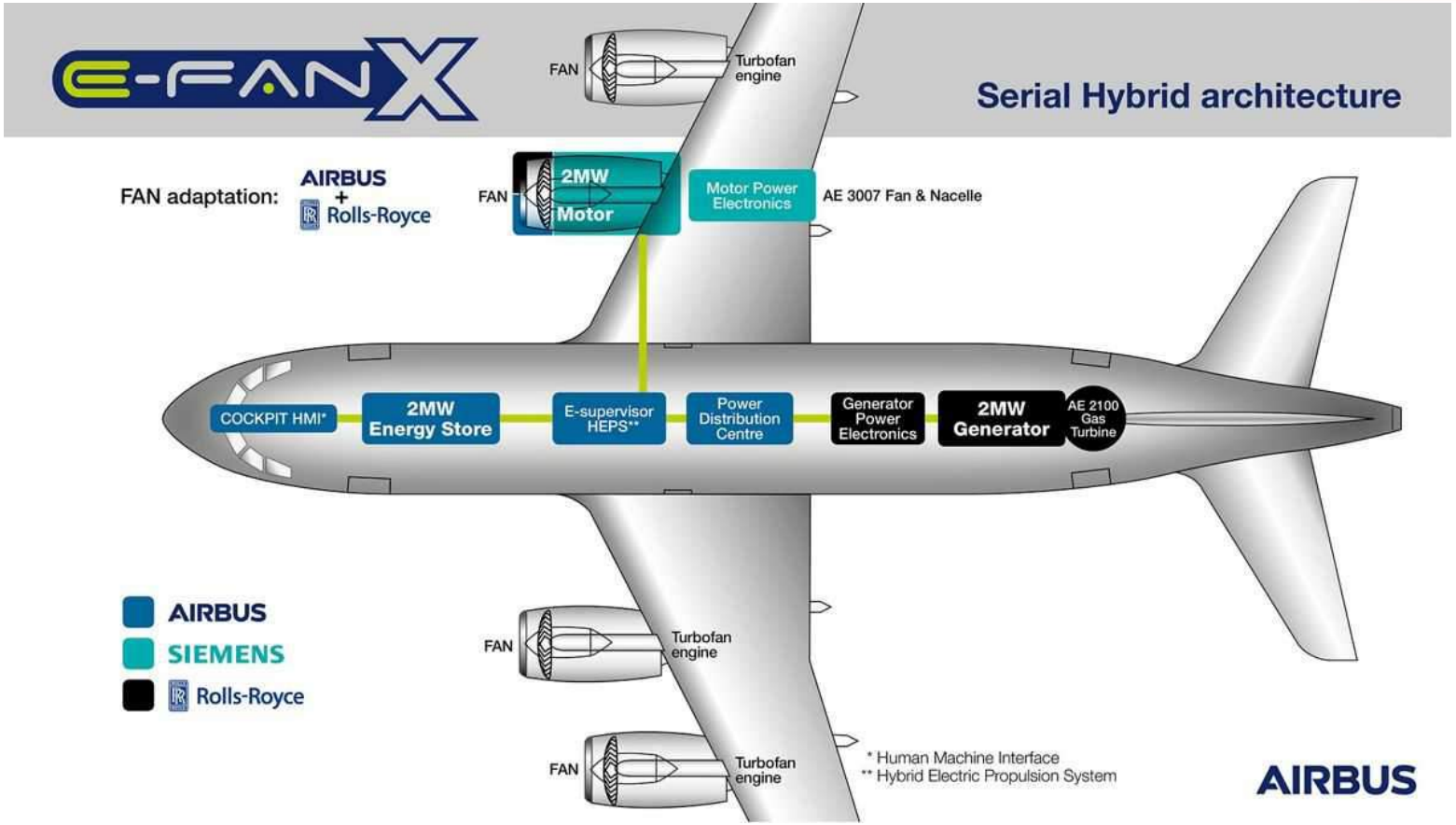
Turbo-electric Distributed Propulsion (TeDP concept)



16 x 3MW distributed superconducting electrical propulsors

https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170002633.pdf

E-FanX



https://airbus-h.assetsadobe2.com/is/image/content/dam/corporate-topics/innovation/future-concepts/INFOGRAPHIC-E-Fan-X.jpg?wid=1196&fit=fit,1

Synergy with marine electrical systems

University of Strathclyde Engineering

Electric Ships - Diverse Applications

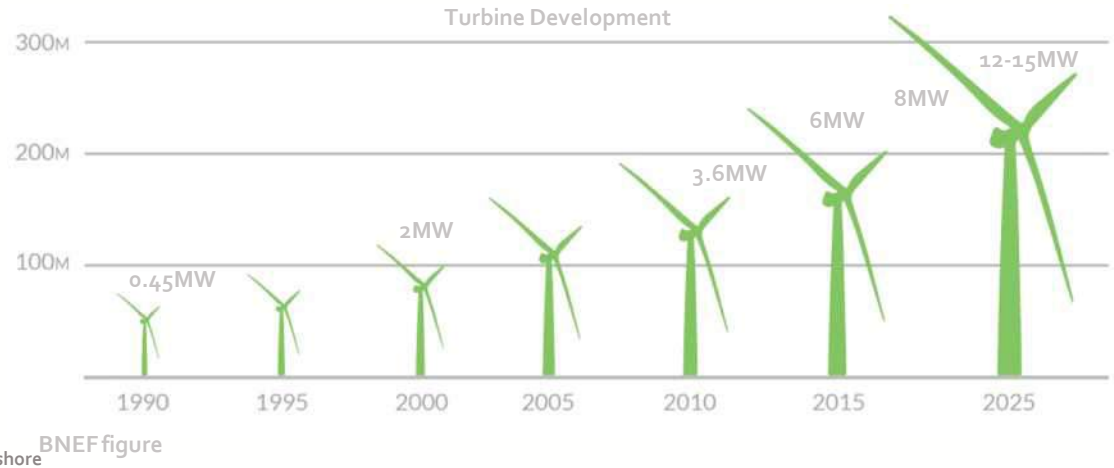
University of Strathclyde Engineering

High Power, Low Power Density

High Power, High Power Density

Both use **40 MW** of Electrical Propulsion

The growth in wind energy generation



Source: 4C Offshore

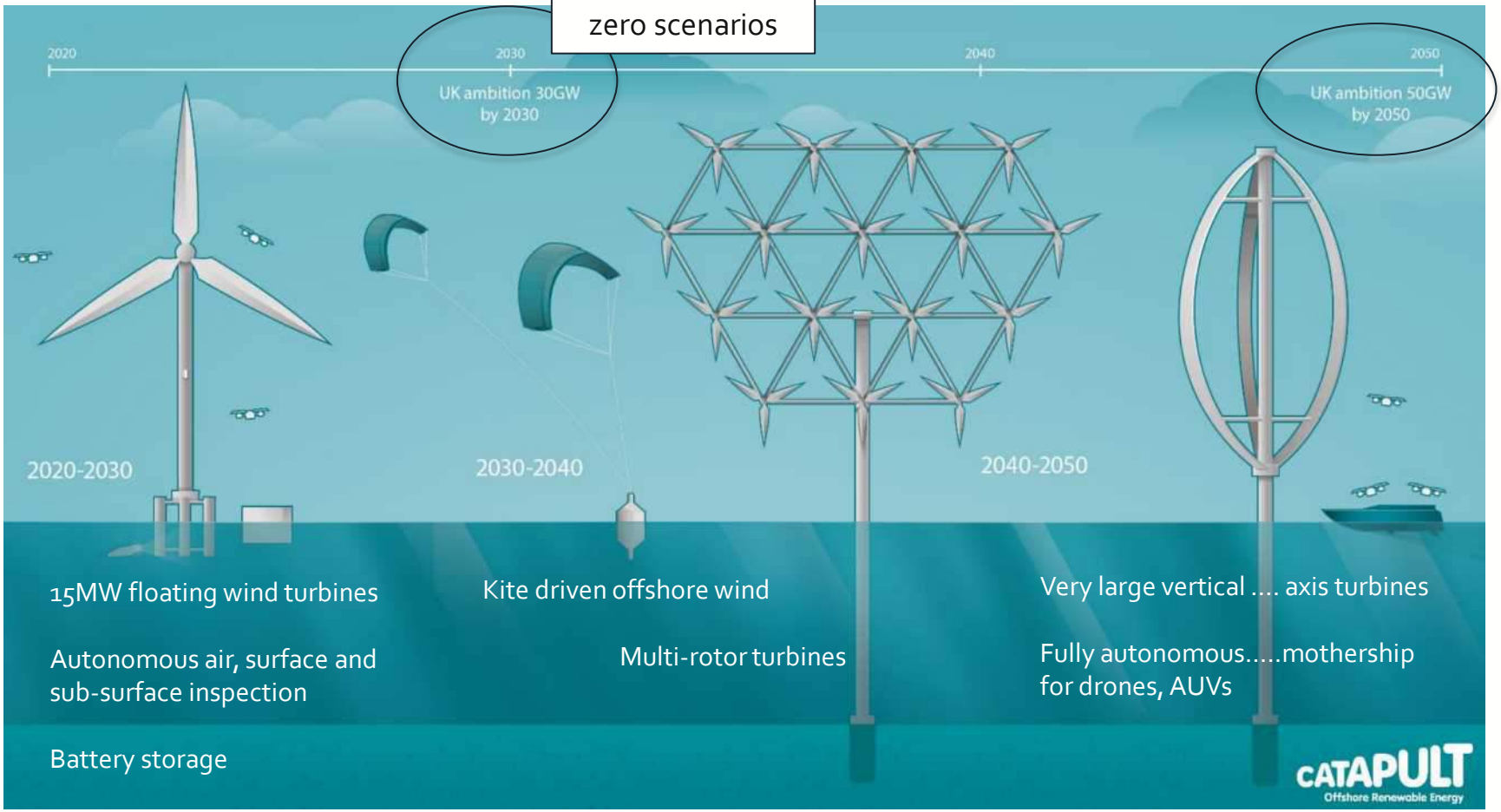
- 12MW turbine testing at ORE Catapult facilities in Blyth this year
- 107m blades, 220m rotor diameter

- Offshore wind costs reduced 50% in 3 years and still falling
- **2000 offshore wind turbines** in UK waters today
- **4000 by 2030,** but getting much bigger

- **£2.5 trillion investment in wind energy globally by 2040**

The Windfarms of the Future

Moving to 35GW in the CCC net zero scenarios



A step change: Floating Wind

The World's first floating wind array

University of Strathclyde Engineering

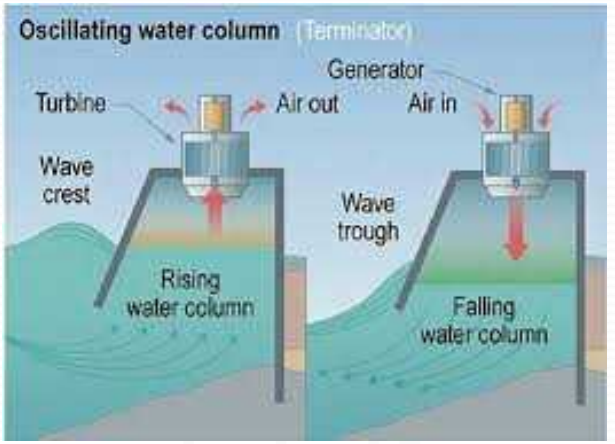
5 x 6MW Floating Spars installed in 2017 off Peterhead (Courtesy Equinor)

Floating wind from 2003 to 2018!

Wave Energy Scaling 100kW – 2MW

University of Strathclyde Engineering

ESRU DEPARTMENT OF MECHANICAL & AEROSPACE ENGINEERING

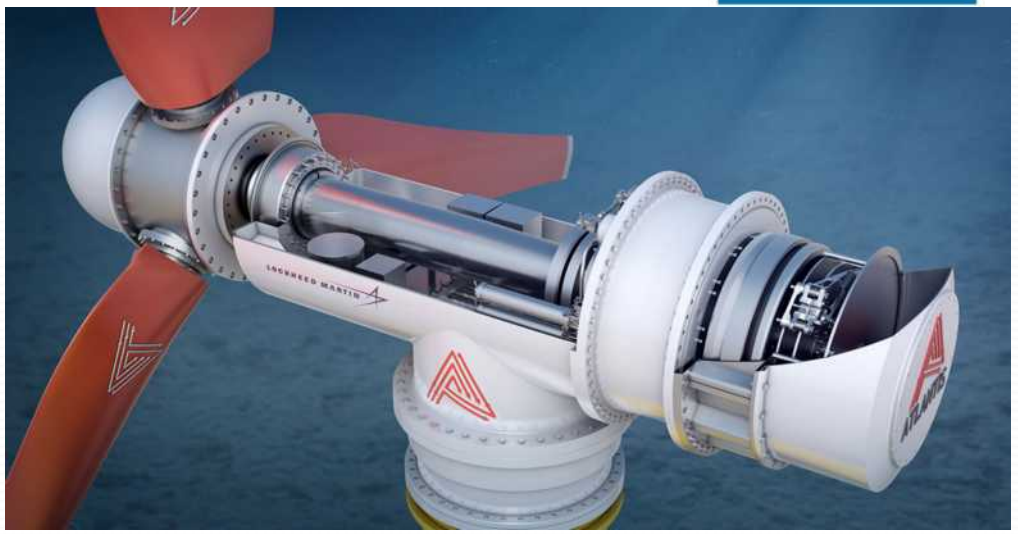


* Images courtesy of
Ocean Energy Buoy (Ireland)

Tidal Energy: Nearing Commercialisation

University of Strathclyde Engineering

ESRU DEPARTMENT OF MECHANICAL & AEROSPACE ENGINEERING

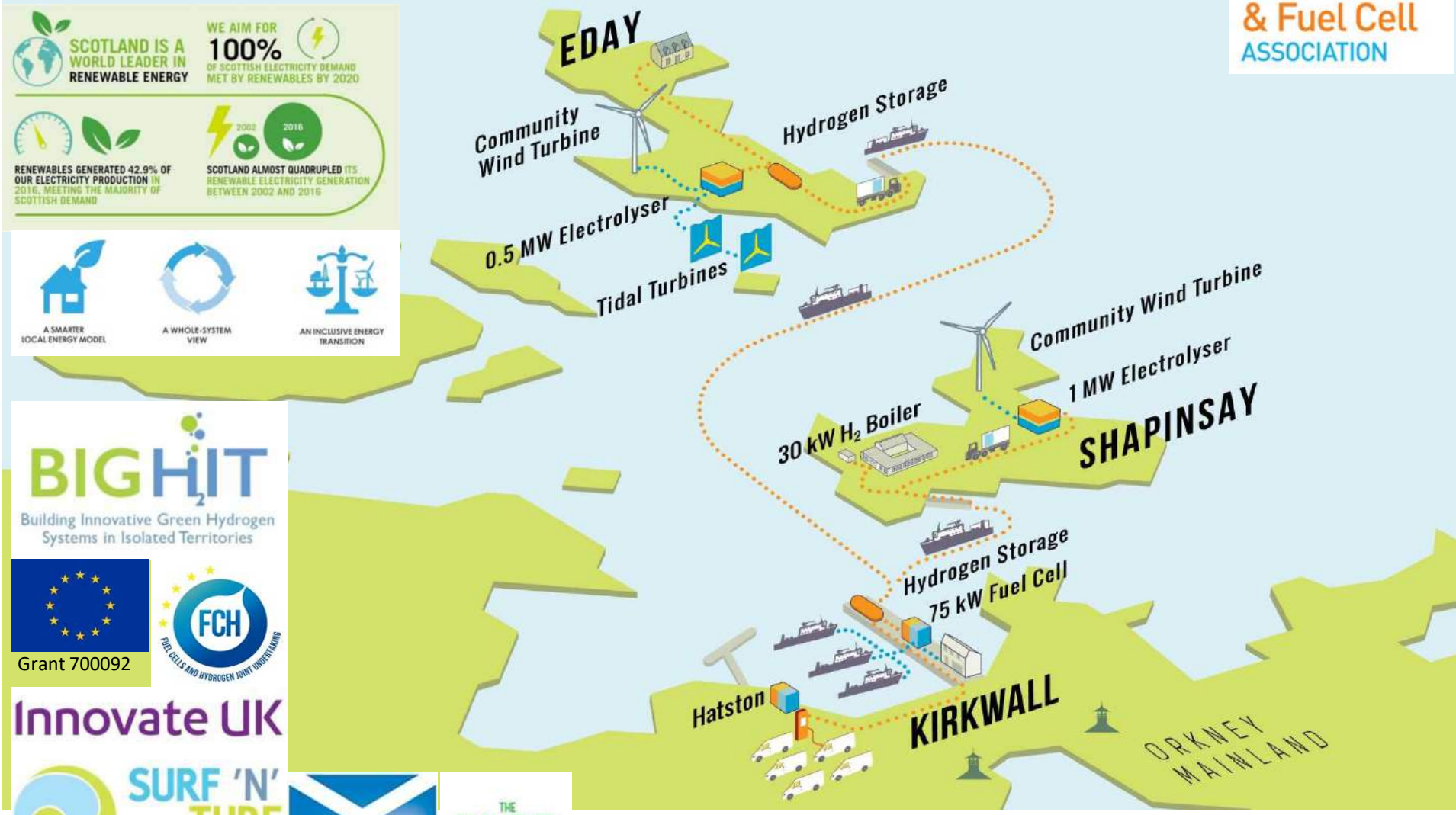


* Images courtesy of
Atlantis Resources & Lockhead Martin

Beyond the horizon…

.... vision from the marine engineering / naval sector

H2 in Scotland Today: Orkney Islands



BIG H2IT
Building Innovative Green Hydrogen Systems in Isolated Territories

Grant 700092

Innovate UK

SURF 'N' TURF
Tide | Wind | Hydrogen

The Scottish Government

THE CHALLENGE FUND

SCOTTISH Hydrogen & Fuel Cell ASSOCIATION

Scotland: Scaling up with Green & Blue H_2

Orkney

Offshore gas production

acorn
CO_2 Storage Site

East Mey

Miller Gas Pipeline

Atlantic Pipeline

Goldeneye Pipeline

St Fergus

Inverness

Peterhead Port

Aberdeen

Offshore Wind for Hydrogen production

National Transmission System (NTS)

Methil

Grangemouth

Glasgow

Edinburgh

CO_2 from H_2 production hub

Around 35% of all UK natural gas comes onshore at St Fergus - an ideal site for a major H_2 production hub. H_2 at St Fergus can be fed directly into the gas grid from blending and decarbonising gas.

Pale Blue Dot.

acorn
A low cost, low risk, clean growth catalyst.

+

Scottish Government's Energy Strategy & Climate Change Plan

…and implications for Cities / Communities…

Aims for energy policy

Scotland's Draft Energy Strategy

'Whole-system' view

- Economic modelling, informing view of Scotland's future energy supply and demand
- **Integrated approach to heat, power and transport**
- New 50% 'all energy' 2030 renewables target
- Renewed focus on energy efficiency and energy demand reduction

2050 energy transition

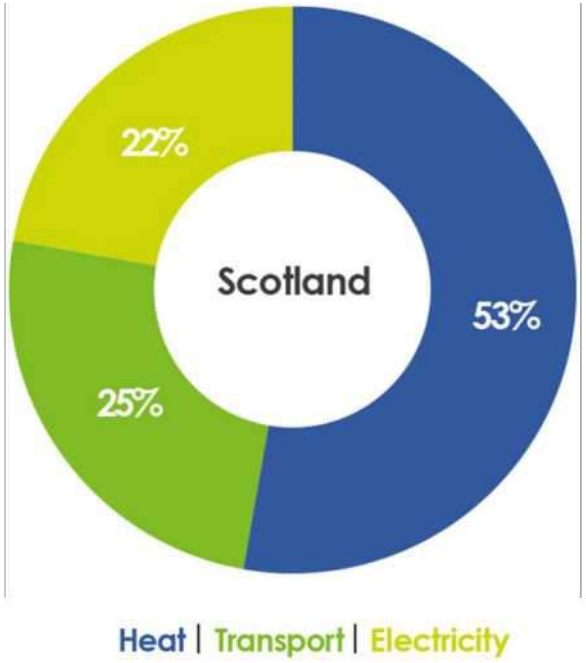
- Long-term plan, consistent with requirements of the Climate Change Plan
- Flexible to future changes in technology and patterns of energy use
- Managed transition of energy supply, post-nuclear

A smarter model of local energy provision

- Encouragement for new localised models of energy supply and use
- Enhanced role for local planning and local ownership
- New economic opportunities of energy storage and 'smart' energy solutions

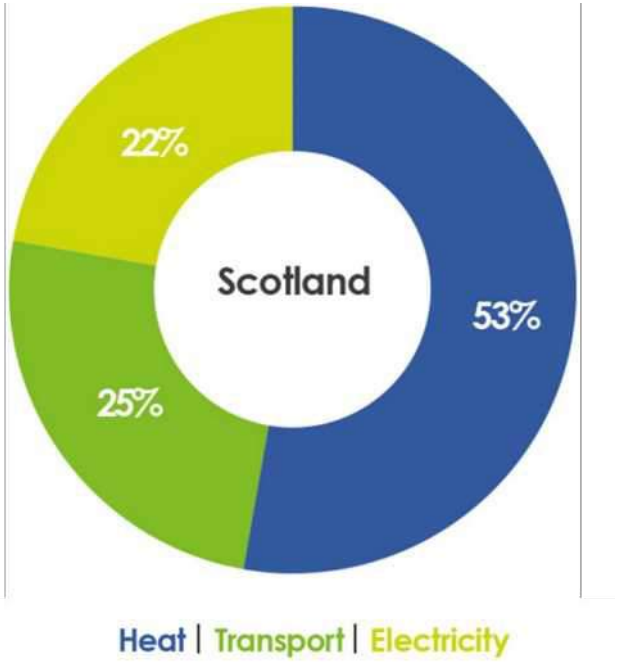
‘Whole system’?

Final energy consumption

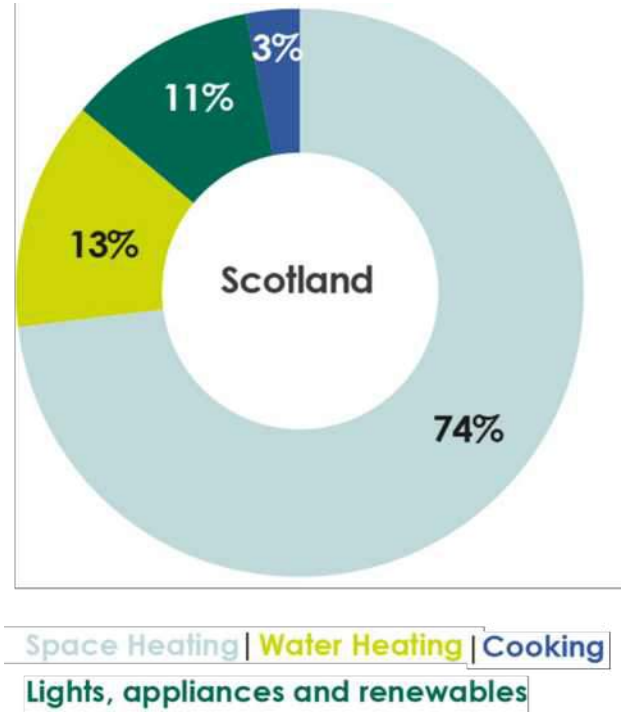


‘Whole system’?

Final energy consumption



Household energy use in Scotland



The Role of Cities

- **Cities are major concentrations of people and resources:**
  - Currently over half of the world's population live in cities
  - Cities are responsible for 75% of the world's energy consumption
  - 80% of world greenhouse gas emissions arise in cities

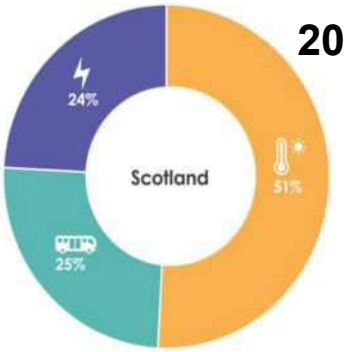
Sustainable Glasgow

Scotland Targets

Scottish Government
Riaghaltas na h-Alba
gov.scot

Petrol and Diesel car and van sales to be phased out by 2032

77% of electricity in 2015 was produced by low or zero carbon sources



By 2032, the equivalent of 50 % of energy consumption to be supplied by renewable sources

In 2015 5.4% of heat demand in Scotland came from renewable sources…

Figure 3.3: Map of Scottish rapid DC chargers (source: zap-map.com). Approved chargers and statistics provided by chargeryourcar.org.uk.

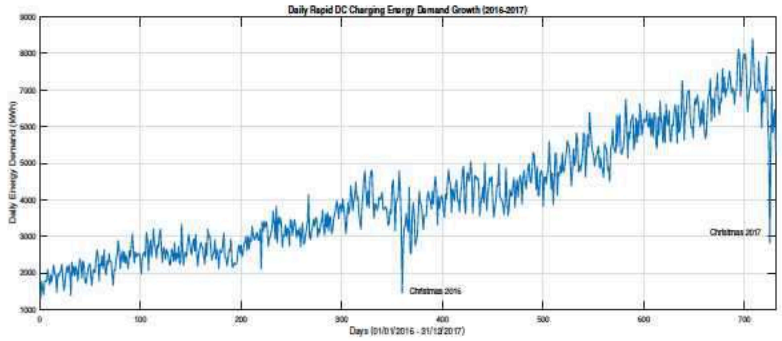


Figure 3.22: Scotland's rapid DC charging network daily energy demand growth across 2016-17.

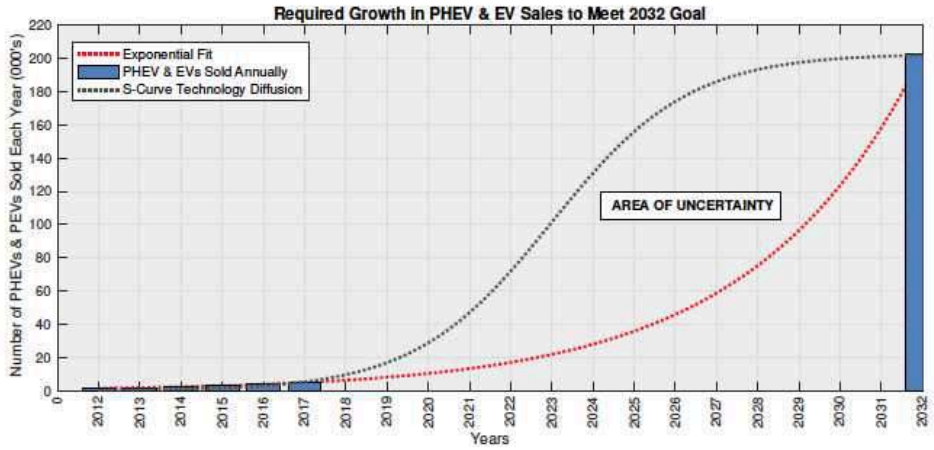


Figure 3.2: Possible Scottish EV sales growth curves from 2017 to 2032 demonstrates trajectory of new car sales necessary to meet 2032 pledge.

Scotland specific rapid DC charging data from the Charge Place Scotland network.

Delivering More Customer Value – Digitally Enabled

Low Carbon Living

Domestic EV Charging

Distributed Energy Services

Access to Public EV Charging

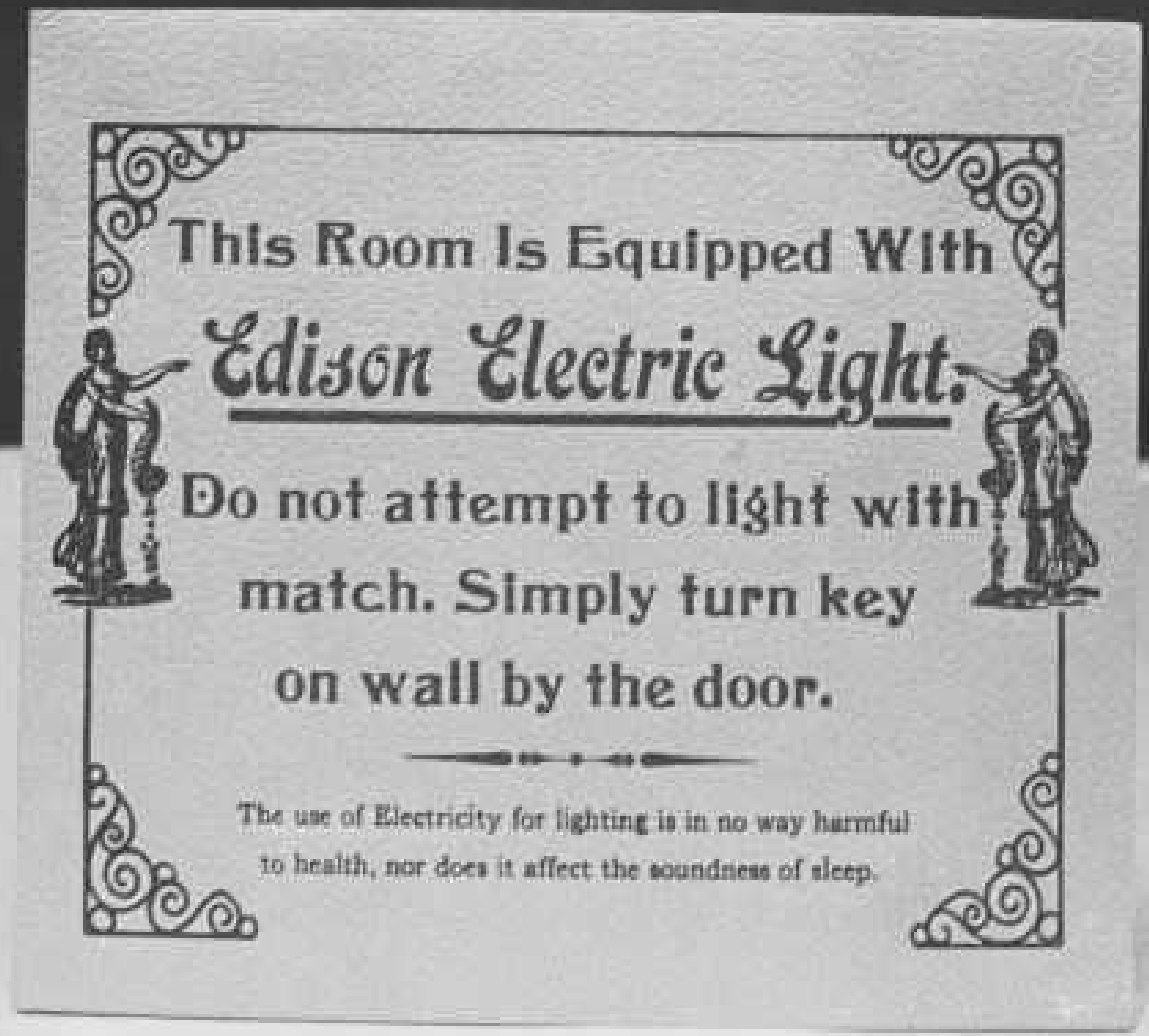
Connected Home Services

Mobile Energy Packages

SMART Appliances

Home Energy Management

Customer Service: Important since the end of the 19thC !



International lessons:

New York REV Projects

New York REV

REV 2030 Goals

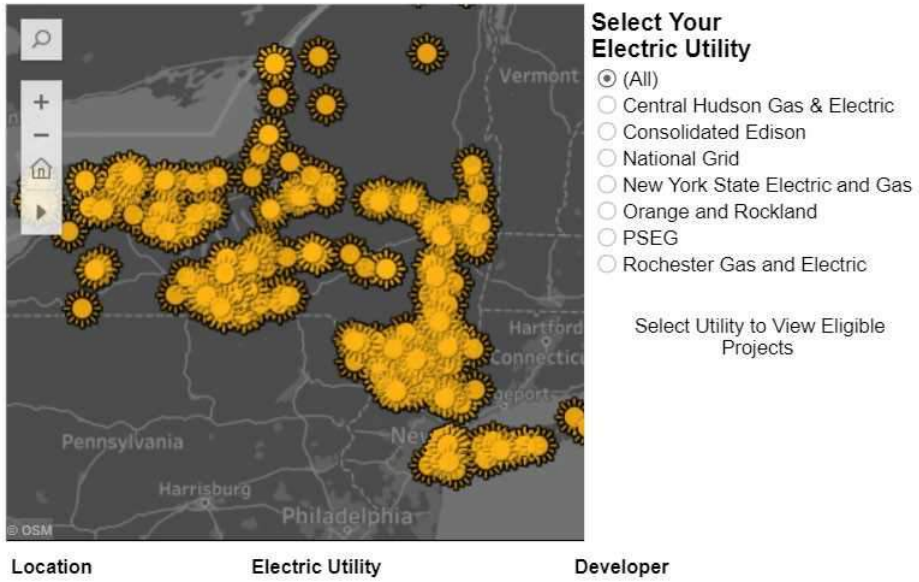
40% reduction in greenhouse gas emissions from 1990 levels	Proposed 70% of NY electricity to come from renewable sources	600 trillion Btu increase in statewide energy efficiency (at source)

Reforming the Energy Vision in New York State:

- Make energy more affordable;
- Support the growth of clean energy innovation;
- Cut greenhouse gas emissions:
  - Gov. Cuomo recently announced that NY State will be 100% Carbon-Free by 2040;
  - This includes 6 GW of distributed solar by 2025 and 3 GW of energy storage by 2030;
- Improve New York's energy infrastructure through Grid Modernization.

Community Solar

- Allowing community members to invest in solar projects regardless of roof space
- Reducing community electric bills and supporting growth of renewables
- Supported by the State through the New York State Energy Research and Development Authority (NYSERDA) through the NY-Sun programme
- Anyone can find and invest/participate in a community solar project across the entire state;
- An Example: PowerMarket operates in Brooklyn, New York
- Supporting the initiative of cutting greenhouse gas emissions and making energy affordable

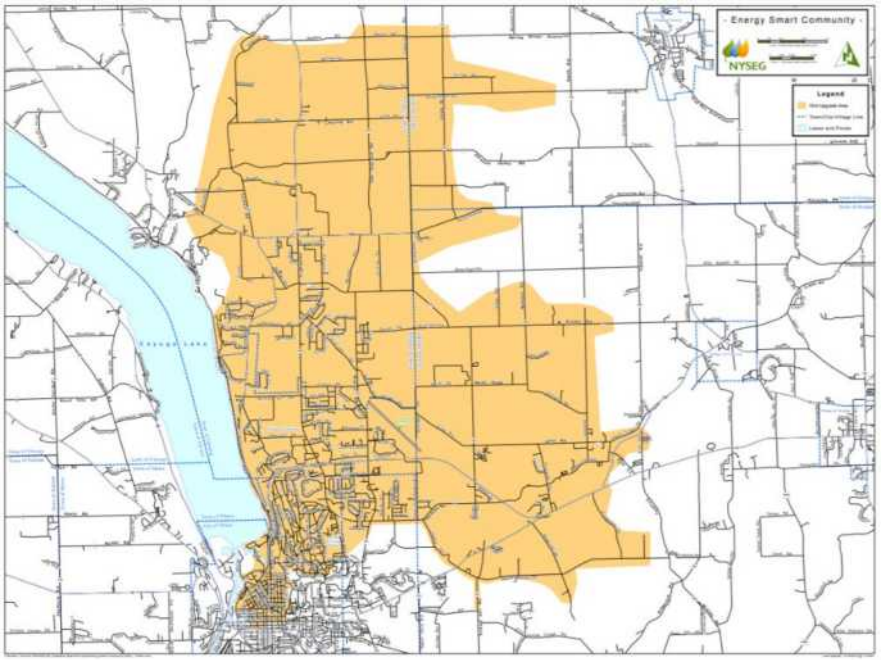


Marcus Garvey Microgrid, Brooklyn

- Hurricane Sandy in 2012 brought large sections of New York City offline, with millions losing power;
- Marcus Garvey Village in Brooklyn, NY, has become its own microgrid;
  - The first in the city focused on affordable housing;
  - Includes 625 apartments and 10 city blocks;
  - 21 of its rooftops have **solar panels** that make up a 480-kW array, coupled with a 400-kW **fuel cell** and a 300-kW **lithium battery**.
  - The community can isolate itself from New York's grid;
  - Reduction of the community's electricity cost;
- Microgrid deployed by Demand Energy, an Enel Co;
- Funding for the microgrid comes partly from Consolidated Edison's Brooklyn-Queens Neighborhood Program (BQNP), a utility program to avert construction of a $1 billion substation with less expensive distributed energy resources;
- This joins other efforts in NYC to construct microgrids and improve the resiliency of the community's access to electricity.

Energy Smart Community, Ithaca

- Avangrid's NYSEG utility has invested in Ithaca's Energy Smart Community (ESC) as a NY REV Demonstration:
  - Complete deployment of smart metering;
  - Automated wireless meter reading Incentives for off-peak electricity usage;
  - Commercial battery storage and electric vehicle projects



- Better system visibility leads to better:
  - Outage recovery;
  - Decision-making and community engagement;
  - Advanced controls.

smarter grid solutions

TAKING A WHOLE SYSTEM APPROACH

What is Whole System thinking?

Energy Systems Catapult – 2050 Scenarios

Introduce a consistent and robust approach to Local Area Energy Planning

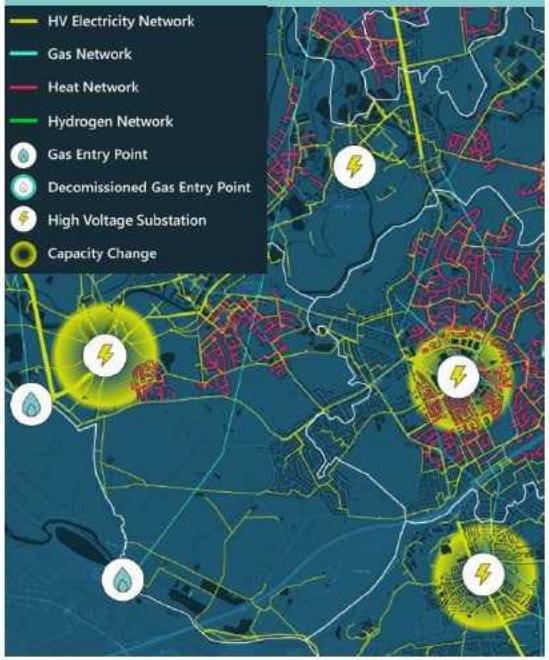
CATAPULT Energy Systems

13.33 x 7.50 in

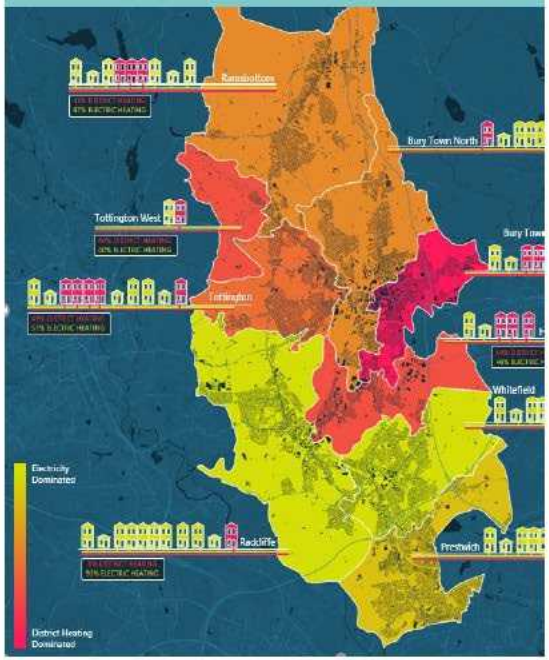
What do Local Area Energy Plans do?

CATAPULT Energy Systems

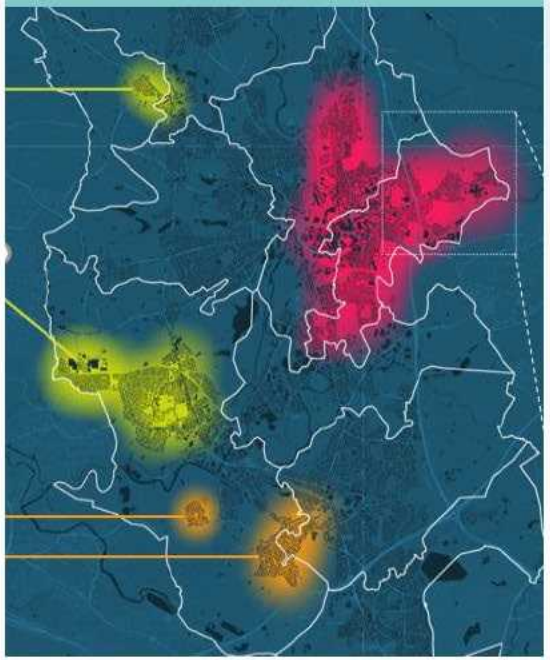
Understand **local options and choices for heat** and other parts of the energy system



Collaboratively develop a **long term evidence based plan** to decarbonise



Resulting in data and insight to **target innovation and deployment** projects



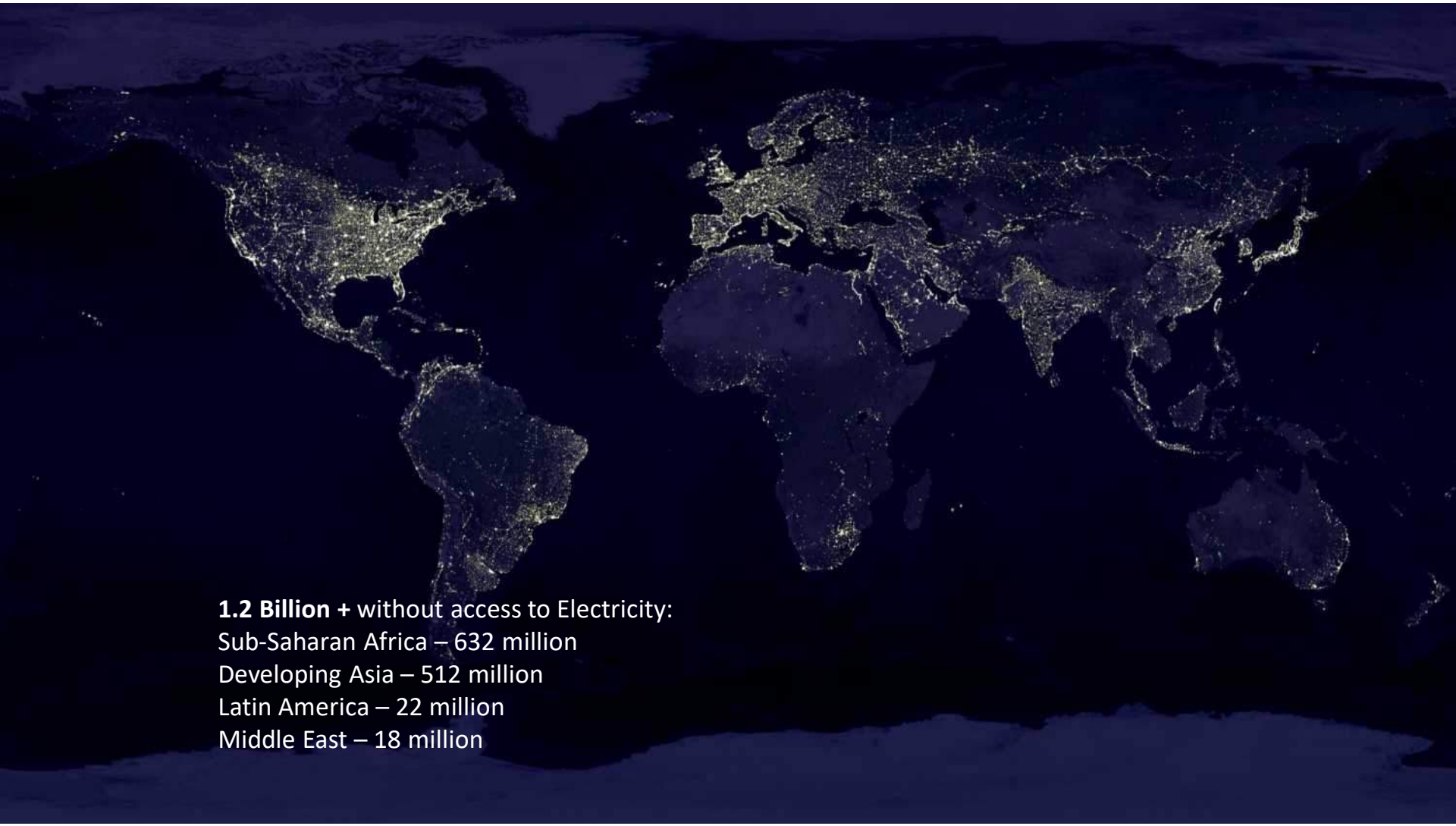
Energy for Development

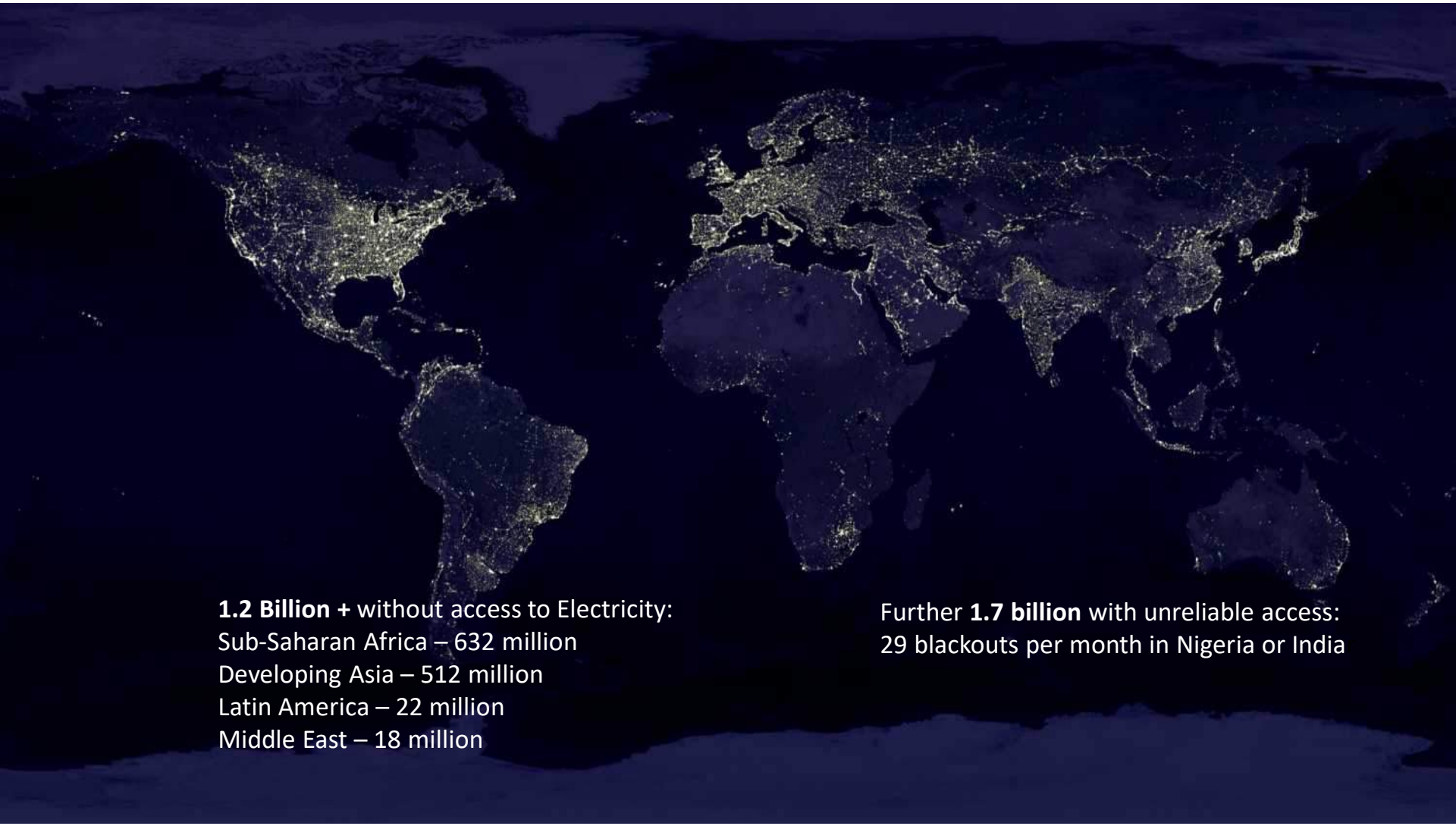
University of Strathclyde Engineering

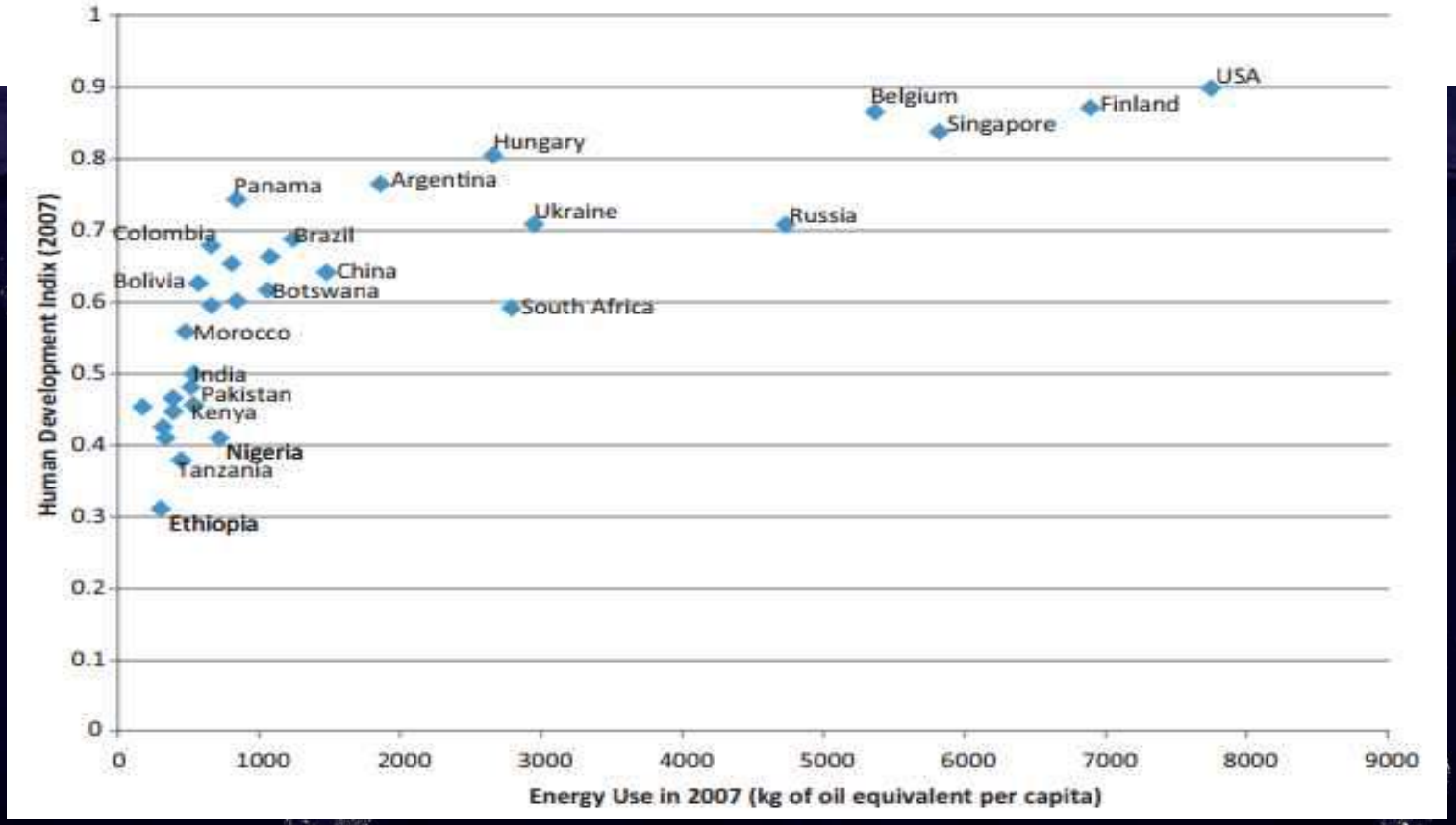
UN Sustainable Development Goals

SDG7 is one of the most interconnected SDGs (**9, 11 & 12** too)

Access to energy doesn't make development happen;
but it does allow development to happen.

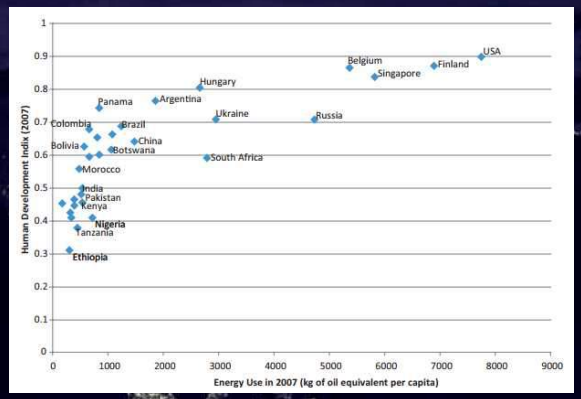

1.2 Billion + without access to Electricity:
Sub-Saharan Africa – 632 million
Developing Asia – 512 million
Latin America – 22 million
Middle East – 18 million


1.2 Billion + without access to Electricity:
Sub-Saharan Africa – 632 million
Developing Asia – 512 million
Latin America – 22 million
Middle East – 18 million
Further **1.7 billion** with unreliable access:
29 blackouts per month in Nigeria or India



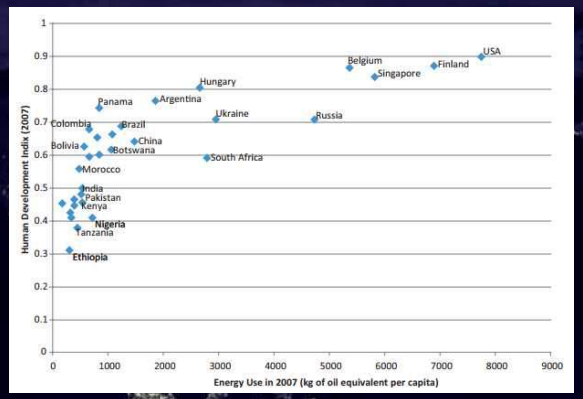
1.2 Billion + without access to Electricity:
Sub-Saharan Africa – 632 million
Developing Asia – 512 million
Latin America – 22 million
Middle East – 18 million

Further **1.7 billion** with unreliable access:
29 blackouts per month in Nigeria or India



1 Billion + without access to Electricity:
Sub-Saharan Africa – 632 million
Developing Asia – 512 million
Latin America – 22 million
Middle East – 18 million

Further **1.7 billion** with unreliable access:
29 blackouts per month in Nigeria or India



7 AFFORDABLE AND CLEAN ENERGY

UN Goal No. 7: Ensure access to affordable, reliable, sustainable and modern energy for all

1.2 Billion + without access to Electricity:
Sub-Saharan Africa – 632 million
Developing Asia – 512 million
Latin America – 22 million
Middle East – 18 million

Further **1.7 billion** with unreliable access:
29 blackouts per month in Nigeria or India

Energy Access Levels

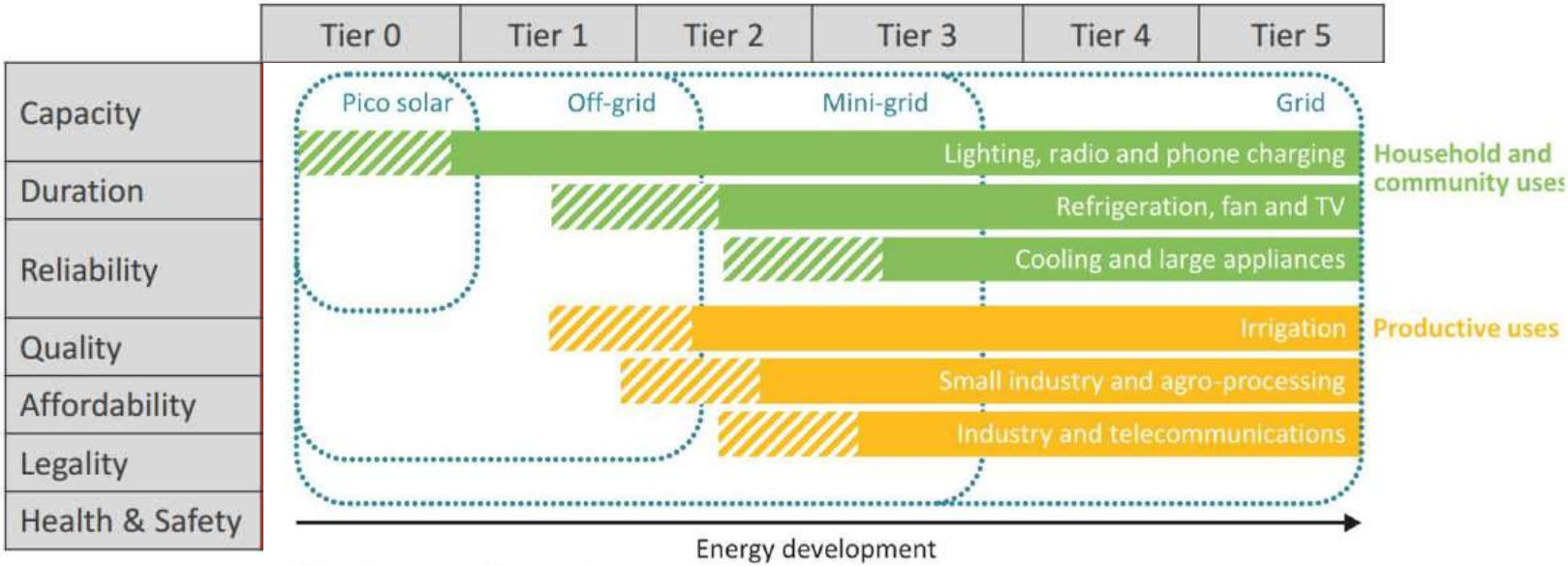
Candles / Kerosene

Pico Solar Products

Solar Home Systems

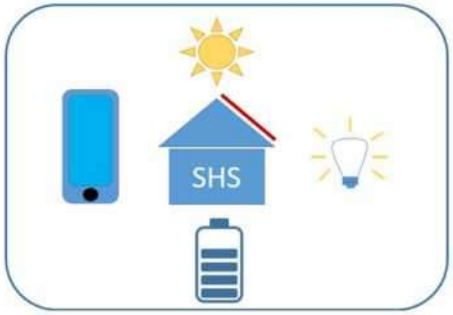
Minigrids

National Grid



Source: ESMAP: A New Multi-Tier Approach to Measuring Energy Access, 2014

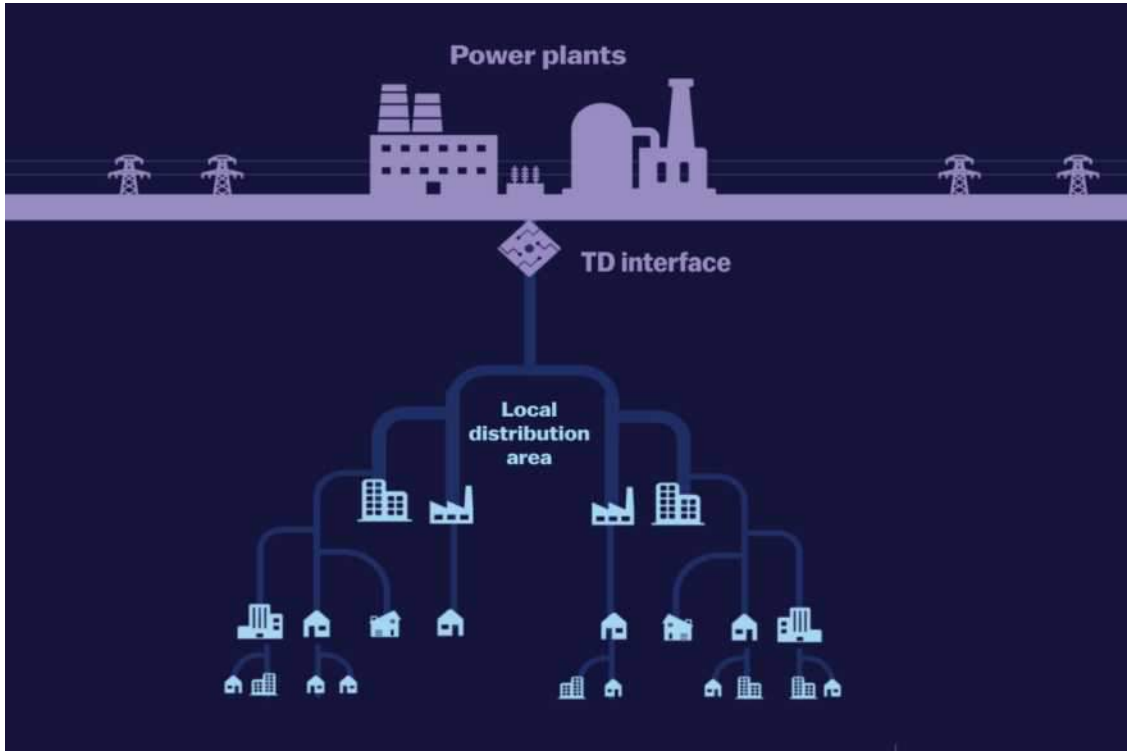
Bottom-Up Electrification



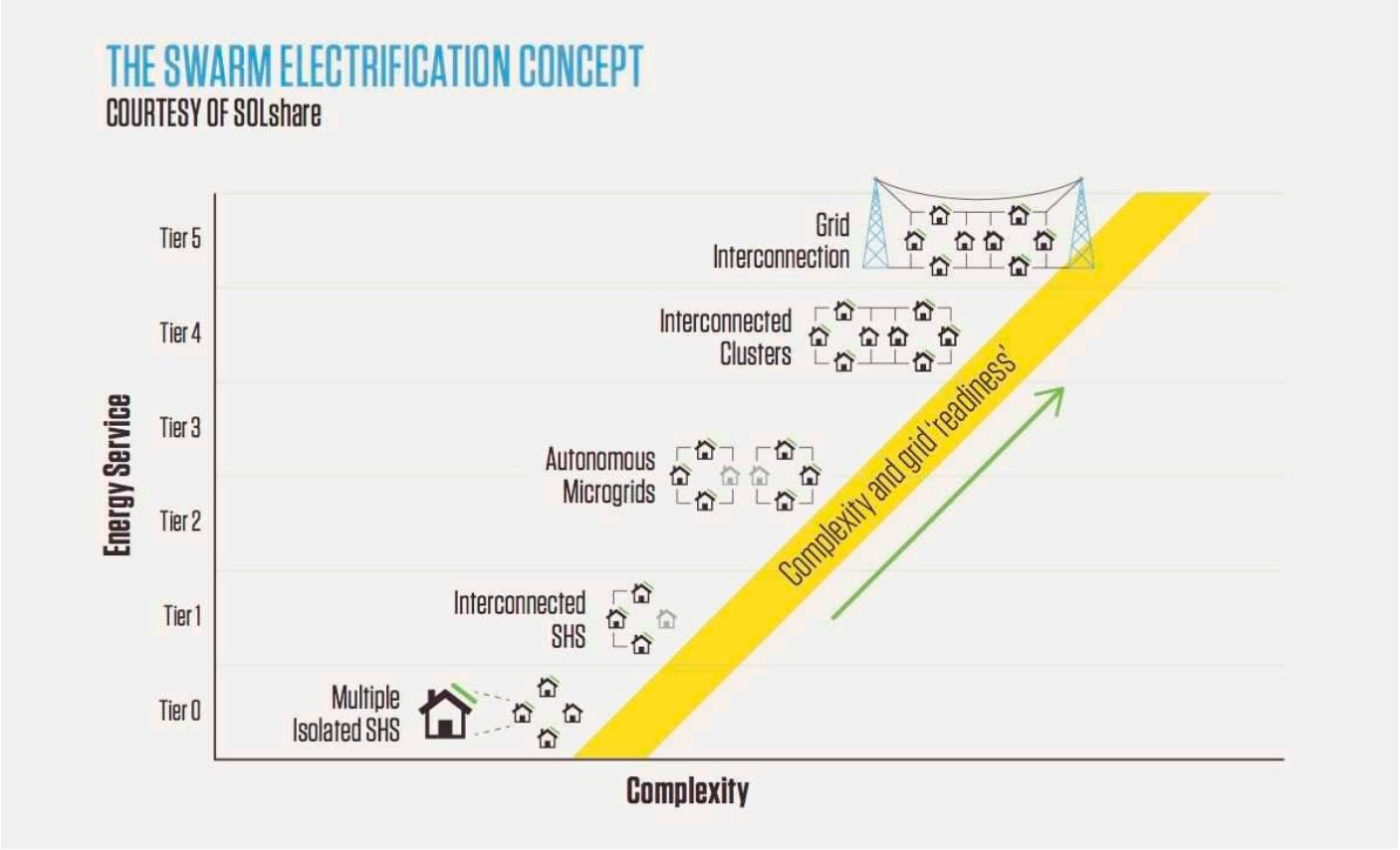
SHS – solar home systems

	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Capacity	No electricity	1-50W	50-500W	500-2000W	>2000W	
Duration	<4hrs	4-8hrs		8-16hrs	16-22hrs	>22hrs
Reliability		Unscheduled outages			No unscheduled outages	
Quality		Low quality			Good quality	
Affordability	Not affordable				Affordable	
Legality		Not legal			Legal	
Health & Safety		Not convenient			Convenient	

Top-down Electrification – Traditional approach of Developed Nations



Bottom-up (Swarm) Electrification – Future for Developing Nations?

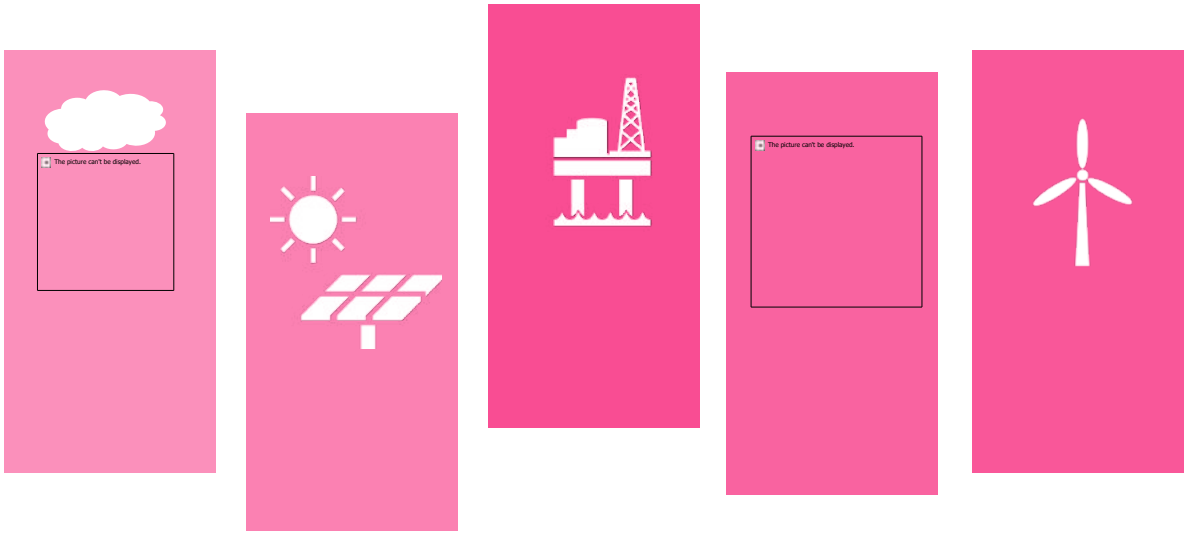


O&G industry faces unprecedented challenges…

The pace of change is only accelerating

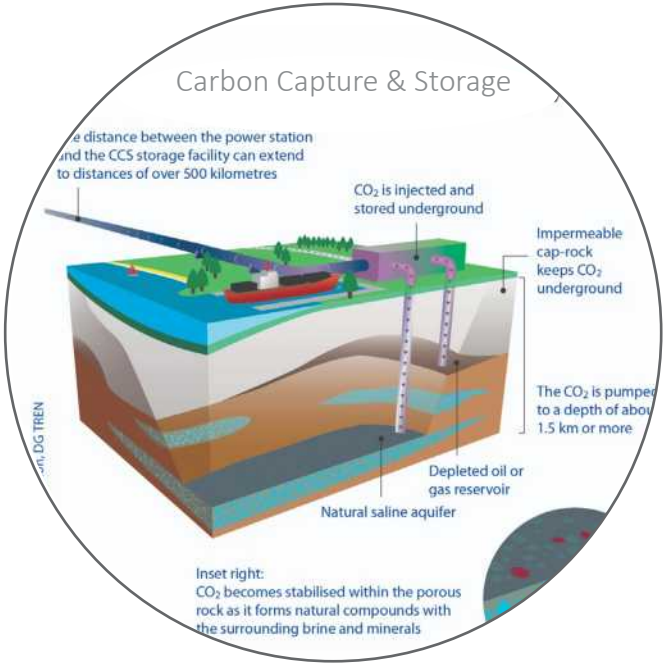
OGUK

All set within the context of the ***energy transition***



The energy transition is happening now with our energy mix becoming much more diverse..

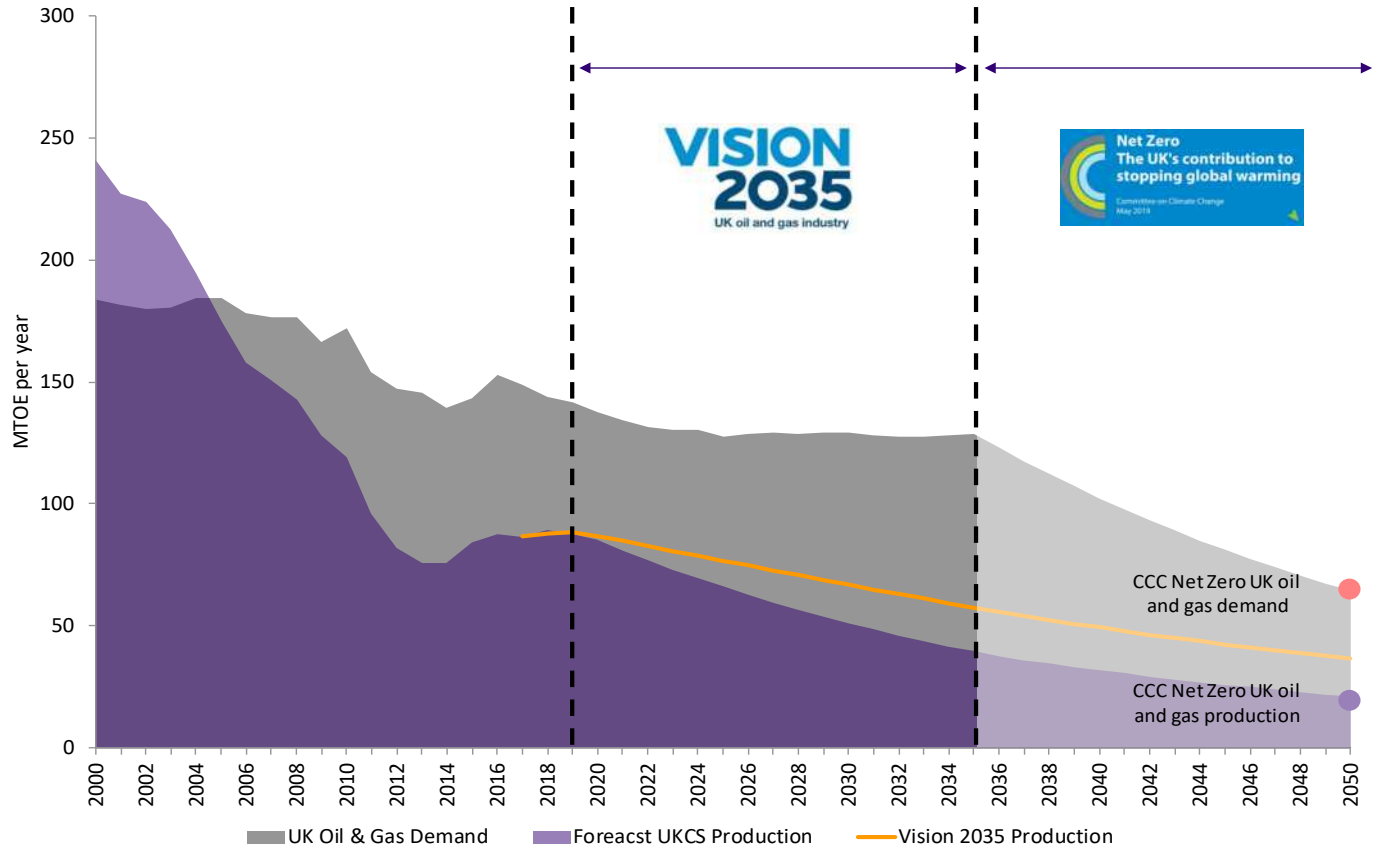
O&G industry can be part of the solution to delivering the energy transition and achieving net-zero emissions



OGUK

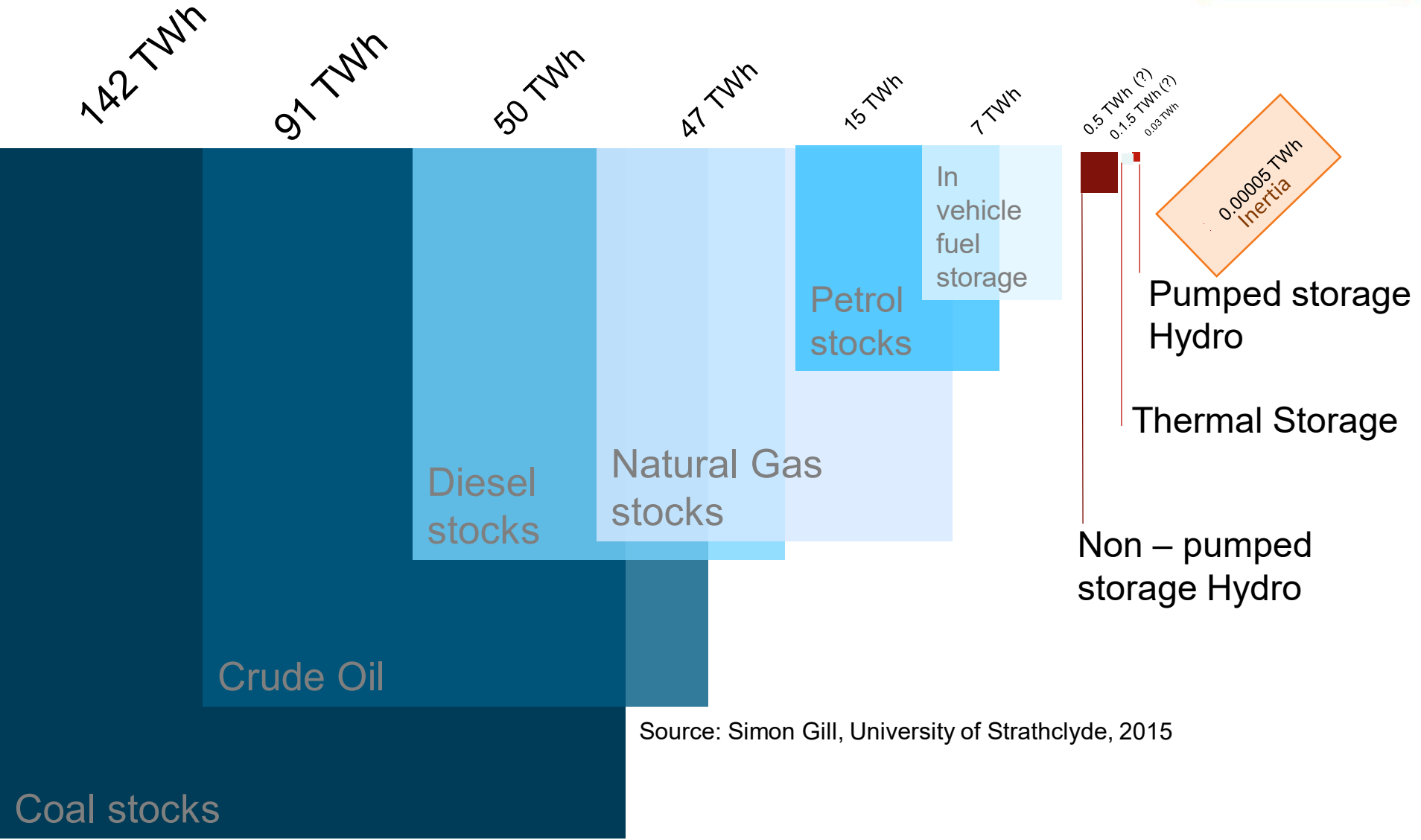
Energy Sovereignty: As much of the UK's oil and gas demand as possible should be met by domestic supply

Projected oil and gas demand in the net zero projection



OGUK

Storage in the UK



Source: Simon Gill, University of Strathclyde, 2015

Not just Lithium Ion Batteries…..

University of Strathclyde Engineering

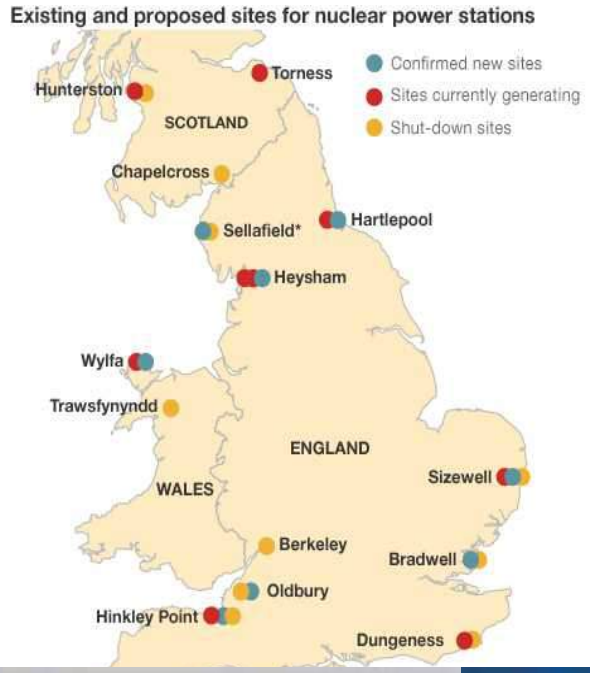
Materials and technologies

- Lithium ion
- Flow batteries
- Pumped storage
- Compressed air
- Flywheels
- Superconducting Magnetic Energy Storage (SMES)
- Heat stores
  - Hot water tanks
  - Concrete blocks
  - Phase change materials
- Hydrogen

Characteristics

- Energy storage capacity
- Energy density
- Charge and discharge rates
- Round-trip losses
- Parasitic losses
- Maximum depth of discharge
- Number of charging cycles
- Capital cost
- Relocatability
- Disposal cost
- Safety

UK Nuclear Power



Existing Nuclear is 20% of UK Generation:

- 7 AGR Stations, 14 Reactors;
- 1 PWR ;
- 8.4 GWe

AGR Stations

WORLD NUCLEAR ASSOCIATION

Nuclear New Build

- 450 nuclear power reactors operating in 30 countries;
- Capacity 400 GWe;
- 2017 providing 2,506 billion kWh, over 10% of the world's electricity;
- 50 power reactors are currently being constructed in 15 countries, notably China, India, Russia and the United Arab Emirates;
- All 50 are state supported.

Barakah new build in UAE

The Opportunity:

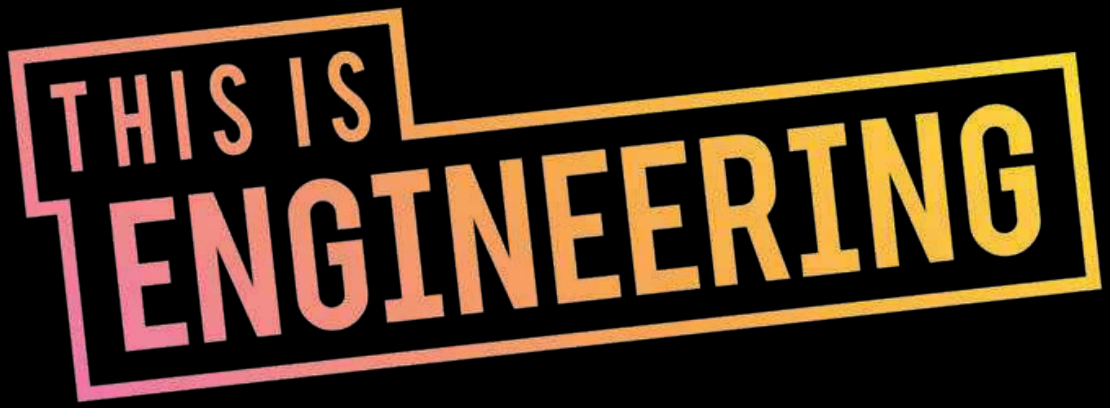
- Zero Carbon Generation;
- Stable Base Load;
- Relatively Low Operating Costs;
- Could be sustainable via Fast Reactors;
- Opportunity for creating employment, and exports;

The Challenge:

- Licencing Process;
- Capital Costs;
- No UK state funding;
- Other Technologies are improving rapidly;
- Societal acceptance, Accidents do happen;
- Nuclear Waste handling and disposal;

Characteristics of Engineering in the UK & Developing the Next Generation of Engineers

- >20% UK Gross Value Added, 50% exports
- Critical to addressing global challenges
- Annual shortage of 59,000 engineers
- 12% female
- < 8% BAME
- **The attraction and development of talent is essential**



www.ThisIsEngineering.org.uk

@ThisIsEng

Final Comments

- Need for International & National Leadership, Vision and Innovation
  - 1926 Weir / Electricity Supply Act – need similar leadership now
  - Digital engagement is turning Consumers into 'Pro-sumers'
  - Cities and local energy participation / ownership will change model - Democratisation
  - The Market is being disrupted / disintermediation

    e.g. BP,

    fast EV Charging, Energy Suppliers; Shell acquiring DNO; DSO migration

- Energy Trilemma (Quadrilemma) must be resolved – climate change pressures are prevalent – (As per Stern Report – we can build new industries and economies as we address CC)

- There is growing recognition that a "systems architect" is required for energy – locally, nationally and internationally
  - However, we need to "keep the lights on" as we evolve the systems - Black Start !

- Importantly – there is an urgent need for action, investment and collaboration now – 2050 is ever closer……. BUT :

Conclusions

Nonetheless, with all these challenges…..

- We should grasp the opportunity with the spirit of **purpose & entrepreneurship** that we saw at the end of the 19thC and beginning of the 20thC (c.f. Edison, Westinghouse, Weir, Page)
- We are in the midst of a historically defining period for the development of international Energy Systems and the Energy Transition
- The acceleration of energy, sensing and data technologies are mirroring “Moore’s Law”
- There has never been a more exciting time for power and energy systems
- This is the challenge that will attract young people into engineering, applied sciences and technology

Energy: Challenges and Opportunities

energy technology partnership

Thank You