Mark's Blog
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Analysis of National Grid Future Energy Scenarios 2022

Summary of Findings

National Grid's Future Energy Scenarios 2022 (NG's FES 2022[1]) is a small step forward on their 2021 document. It contains broader, for example considering aviation, shipping and railways (albeit only in terms of emissions, not energy consumption). We agree that "Whole system thinking helps decarbonisation" (p80); indeed, without it, decarbonisation will be unaffordable, impractical, excessively disruptive, unreliable and un-resilient.

Re-naming the "Steady Progression" scenario as "Falling Short" is an excellent change as it says exactly what that scenario does.

National Grid provides a number of focal areas, which are addressed in turn:

- Focus on consumers,
- Policy and delivery,
- Consumer and digitalisation,
- Markets and flexibility,
- Infrastructure and whole energy system,
- Navigating a fair transition to Net Zero

Electricity Storage

Despite many grave errors in the modelling that understate the need for storage, FES 2022 compliant scenarios require 32-52GW of electricity storage. Comparing the total GW and GWh of storage yields an average storage duration of 3.6 hours for the three Net Zero compliant scenarios. Given that nearly all battery storage is typically 1 or 2 hours, also stated in the report, that means that at least as much longer-duration storage is needed, of 4-12 hours duration.

Hydrogen

Despite omitting many of the largest potential uses for hydrogen, FES 2022 nevertheless identifies a huge need for it, widely varying between scenarios, of up to 431TWh hydrogen. Adding in those uses (such as industrial and chemical processes, synthetic fuels and complex compounds like ammonia) would greatly increase the total need for hydrogen, even if some of the less-likely uses cited in the scenarios were discounted.

Focus on Consumers

The focus on "consumers" is still as strong and misleading as ever.

[1] https://www.nationalgrideso.com/future-energy/future-energy-scenarios

1. Because a timescale is never mentioned, it means "consumers of today" at whose altar we sacrifice those of tomorrow, always seeking "least-cost options" for now, which eclipse all efforts at medium- and long-term considerations.
2. The focus on the energy cost is the opposite of a focus on consumers because the cost of generating electricity makes up 20-25% of today's electricity bills, down from 75-80% a decade ago, and dropping (which I analyse elsewhere this month). The rest is made up of the charges, levies and energy system costs that are escalating exponentially due to poor electricity system regulation and contracting[2].

Policy and Delivery

Policy and Delivery focuses on demand side strategy (both reducing demand and balancing demand profiles), energy efficiency (again reducing demand) and a focus on heat, which is about heat itself, largely ignoring how the energy is generated, distributed and balanced to produce that heat where and when needed. These are tickling the edges of the challenges, skirting around the edge of the big issues which are generation, storage, the transmission and distribution systems (network size and shape), integration of system and network thinking, enabling projects to benefit from improving overall system costs etc., reliability and resilience. Focusing so heavily on demand abdicates the challenge of ensuring sufficiency and security of supply.

Consumer and Digitalisation

This again misses the point. Digitalisation (ungrammatical as it is, it should be digitisation) merely optimises the use of energy in the system; it doesn't ensure that there's enough there in the first place, or with suitable reliability, resilience or energy security. It cuts margins to the bone, virtually eliminating the ability of consumers to change behaviour or systems to react if there is some substantial change, such as a faster or slower roll-out of EVs, or energy supply challenges.

While it's important to educate consumers and help them change for Net Zero, the effects of most such initiatives (e.g. Smart Meters [which can at most reduce consumers' bills and network peak demand by ~5% according to their own publicity or, more realistically, 1-2%[3]], though smart-charging EVs [a much more marginal exercise than claimed[4]] is additional to that figure) is at best marginal. Other experts looking at an average £693 increase in energy bills think that as much as a mere £75 could be saved, in comparison with the price cap expected to rise to £2,800 by October – that's just 2.7%[5] and assumes that all consumers will have the time, inclination, incentive and ability to maximise their benefits: of those that have the inclination and ability, how many are earning little enough for £75 p.a. to be sufficient incentive?

[2] https://www.storelectric.com/challenges-of-the-electricity-transition/
[3] https://www.thisismoney.co.uk/money/bills/article-4297996/Can-smart-meter-lower-energy-bills.html
[4] https://www.storelectric.com/vehicle-to-grid-and-shared-mobility/
[5] https://www.express.co.uk/finance/personalfinance/1618390/smart-meter-reduce-household-bill-uk-2022

Markets and Flexibility

Again, the focus on flexibility without duration misses the question of energy security. Omitting grid stability misses the questions of reliability and resilience.

Locational signals are good but, if taken to National Grid's natural conclusions, will sub-divide our 50-100GW grid (depending on whether we're looking at now or the future) into hundreds of tiny sub-markets which, of their nature, will disadvantage the large and broadly-capable solutions that the grid most needs. Moreover, some of the technologies most essential to Net Zero (e.g. wind, large-scale long-duration inertial storage) have to be put in specific regions; penalising them inordinately for doing so would make the energy transition unachievable.

And market participation is geared around bringing into the grids ever increasing numbers of participants at the distribution level, small scale and short duration, which are exactly what is driving up the costs and hurting the reliability and resilience of the transmission grid.

Infrastructure and Whole Energy System

The whole-system thinking that is presaged by National Grid's Pathways to 2030 Holistic Network Design document (which I analyse elsewhere this month) is far too short-term to achieve the objectives without wasting a fortune on future re-work and without building enough grid to encourage new Net Zero compatible projects to come forward.

Inter-seasonal storage is just an assumed need. And National Grid seeks to jump to addressing it before (a) addressing the long-duration energy storage needs, i.e. 4 hours to 2.5 weeks duration, (b) determining how much seasonal storage is needed or (c) imagining any ways in which to incentivise reserve – which is why, in gas, the UK has just 3 days' reserve as compared with 3-9 months as standard in continental Europe.

Whole system competition is only about delivering something similar to what NG engineers have conceived. There is no concept that others may have ideas, initiatives and projects that offer radically improved alternatives (such as Storelectric's proposal to halve the size of grid needed for each offshore wind farm, with many other linked benefits) or considering any way of sharing the benefits with such project developers.

Navigating a Fair Transition to Net Zero

Without all the considerations above, the transition to Net Zero will not be fair, affordable, reliable or resilient. Despite the section headed such on p13, National Grid is not "seeing the whole picture", excluding, for example:

- Medium- and long-term thinking;
- Large and broadly capable solutions;
- Solutions with cross-over benefits between network and system;
- As well as their many other shortfalls detailed in this document.

Regionalisation

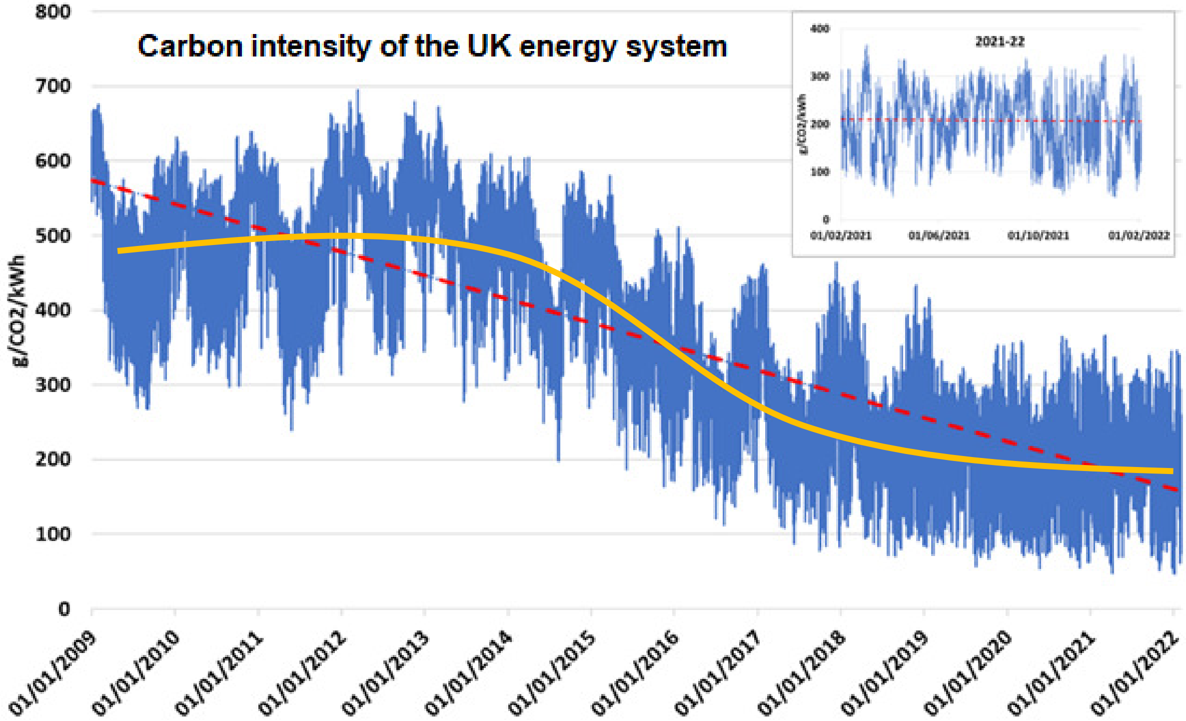
Today the UK has a 50GW grid and (mostly) 50GW markets. There is some, but limited (e.g. TNUoS) regional incentivisation to push developers to think carefully about where they put their proposals.

National Grid wants to greatly enhance these regional signals, which is fine for those projects (e.g. batteries) that can locate anywhere but will make projects without such flexibility (e.g. offshore and onshore wind, large-scale long-duration storage of any type) much harder to fund. And by doing so, it would make the energy transition as a whole unachievable: how can we generate enough power without locating the offshore wind beyond the furthest extremities (north, north-west, north-east and south-west) of the British Isles? How can security of supply, energy affordability and sufficiency, and grid reliability and resilience be achieved (i.e. all those factors together, not just some of them) without large-scale, long-duration, inertial storage?

Another result of regionalisation is to salami-slice the current single markets for most grid services / products, which are 50GW but rising towards 100GW, into numerous mini-markets. Just look at retail to see what that means: reducing volume and variety while increasing costs both of the products themselves and of doing business. Suddenly a GW-scale solution would become so dominant in its mini-markets that they would not be permitted to contract at the scale most suited to their technology.

Net Zero

The energy transition is about replacing hydrocarbons with zero-emissions technologies, so Net Zero technologies must be at the scale of hydrocarbons (i.e. of power stations), or the objective will be missed by a very wide and/or costly margin. The power stations deliver energy, availability / dispatchability, grid stability, reliability, resilience, energy security, Black Start and other capabilities at the same time, indeed they do so concurrently with the same plants; therefore Net Zero technologies must do all these too: otherwise the energy transition will be unaffordable, unreliable and fragile which will lose both public and political support for it.



Source: Future Energy Scenarios 2022

The British grid’s carbon intensity is shown to be decreasing fast. However, that is utter complacency, supported by fitting a straight line as a trend (the red dotted lines): the true trend (orange solid line) is an S shape, which would show that the grid’s carbon intensity largely levelled out from 2019 and shows little sign of further improvement, as shown by the inset graph which flat-lines over the last two years. Indeed, without sufficient large-scale, long-duration, naturally inertial storage, and the regulatory and contractual arrangements to encourage it, little further improvement is achievable. This calls into question whether any of the scenarios, on business as usual, will even come close to Net Zero as it questions whether the power sector would decarbonise at all, let alone by 2035.

Contents

The Energy Consumer

Many of the changes listed are indeed required, and some more: it doesn't list a change for non-business drivers to renewably powered vehicles.

Electricity Demand Overview

The FES 2022 analysis has substantial shortfalls and omissions. In summary, its analysis of the many sources of demand:

- Under-estimates future energy demand:
  - Until recently the grid accounted for ~¼ of all UK energy use, with the remainder being used by heating, transportation, industry and other sectors:
    - Heating will be decarbonised largely by hydrogen (electrolysed using electricity, or chemically formed using electricity) and heat pumps (electricity);
    - Transportation will be decarbonised largely by electrification and fuel cells (hydrogen, as above);
    - Industry will be decarbonised largely by electrification, hydrogen heating and hydrogen processes;
    - Therefore electricity will rise to 75-90% of basic energy supply.
  - NG recognises the efficiencies of electricity use (e.g. 4x more efficient vehicle transmissions) without recognising the inefficiencies up-stream (e.g. of storage or electrolysis) or increased utilisation (mileage has consistently risen, even if total transportation fuel consumption has not due to improving vehicle efficiency; with the after-effects of the Coronavirus, an increasing proportion of transportation is personal vehicles, with decreasing public transport usage).
  - But every sector considered under-states future demand; for example:
    - Consumers are assumed to be unreasonably "prosumers";
    - Digitalisation is assumed to be energy-free;
    - Domestic heating rests on highly questionable assumptions of up-take (constrained by space, as much as anything) and efficiency, and ignores that below certain temperatures heat pumps become progressively less efficient until they stop working;
    - Transportation relies on excessive EV up-take beyond what the planet's resources can support, assumes at least 6x over-optimistic V2G support, and ignores ~30% system inefficiencies;
    - Industrial and Commercial demand concentrates on making plants and processes more efficient but totally ignores the electricity and hydrogen used in creating environmentally friendly fuels, feedstock materials and hydrogen substitution in processes such as iron and steel making.

Residential Consumers

One constant over recent years is "Residential consumers will need to start engaging with Time of Use Tariffs and forms of smart control and automation of energy consumption…" On bills forecast to rise to £2,800 p.a., the potential savings that they advertise are £75, or 2.7%. Few will maximise those benefits. Many (e.g. those with

health and mobility issues) have little opportunity to flex their usage. Of the remainder, those able to engage actively will be earning sufficient for £75 p.a. to be minimal incentive, especially in relation to the time they would spend each year doing so. Therefore the only realistic way of doing so would be to engage automated services that would charge less than one-third of the savings, to manage their demand without continual consumer input; FES 2022 correctly assumes that “automation optimises energy use for residential consumers in the background.”

If one such service were to become very popular, or (as would be reasonably expected) many such services operate at roughly-correlated times, then it would create problems of its own as it switches large amounts of demand. Diverse services would produce correlated actions because they are trying to optimise demand based on identical market signals.

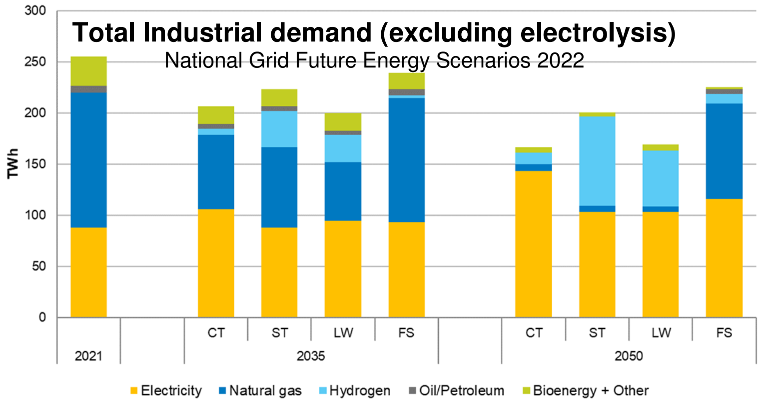
Industrial and Commercial Consumers

The comments below are about industrial consumers. The analysis of commercial consumers is strikingly similar, and so would our analysis be.

“*Some industrial consumers may need to re-locate in some scenarios to areas with hydrogen or Carbon Capture, Usage and Storage (CCUS) technology available to enable them to decarbonise*.” This is entirely correct, and the government needs carefully to consider the incentives necessary for doing so. The best incentive would be an Emissions Added Tax[6], combined with one-off assistance with relocation.

The same measures would support other decarbonisation actions from industry, without giving away competitive advantage to imports from countries that don’t have such concern and concerted action on emissions and climate change exacerbating activities.

Industrial demand for gas is currently 132TWh p.a., nearly all of which is expected to be replaced by electricity and hydrogen (except in the Falling Short scenario, in which it reduces by 30%). Yet electricity demand is not forecast to rise correspondingly, and no account is taken of the electricity required for electrolysis.

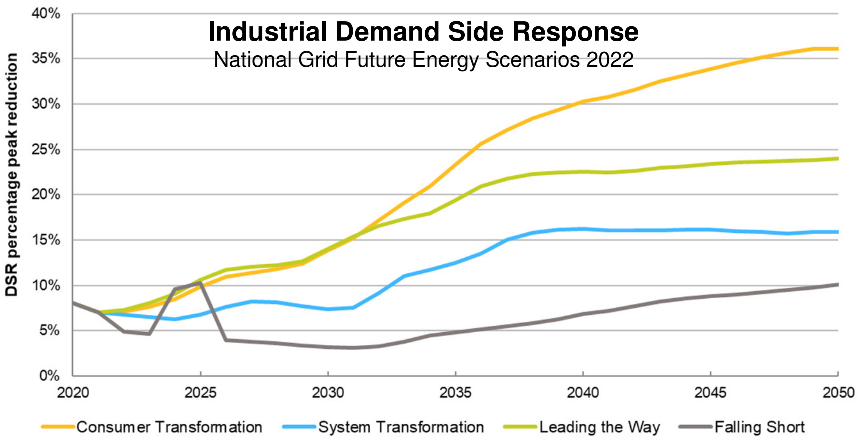


FES correctly draws attention to the seven Zero Carbon Energy Clusters around the country. Unfortunately the agendas of many of these have been deflected by the

[6] https://www.storelectric.com/incentivising-clean-energy/

hydrocarbon lobby into blue hydrogen and CCS, which is not sustainable, discussed elsewhere in this document. But they do support the transition of local industrial and residential consumers to hydrogen and electricity, so are exceedingly beneficial.

The energy transition, as mapped by industrial sector, has curious de-emphasis of hydrogen even though that will be the principal way of decarbonising iron, steel and some other sectors. For example, electric arc furnaces using electrolysed hydrogen (rather than coal) as a reducing agent can be totally emissions-free. Some other chemical pathways will be replaceable with ones involving hydrogen and, for most applications, high-temperature heat will be from that source.

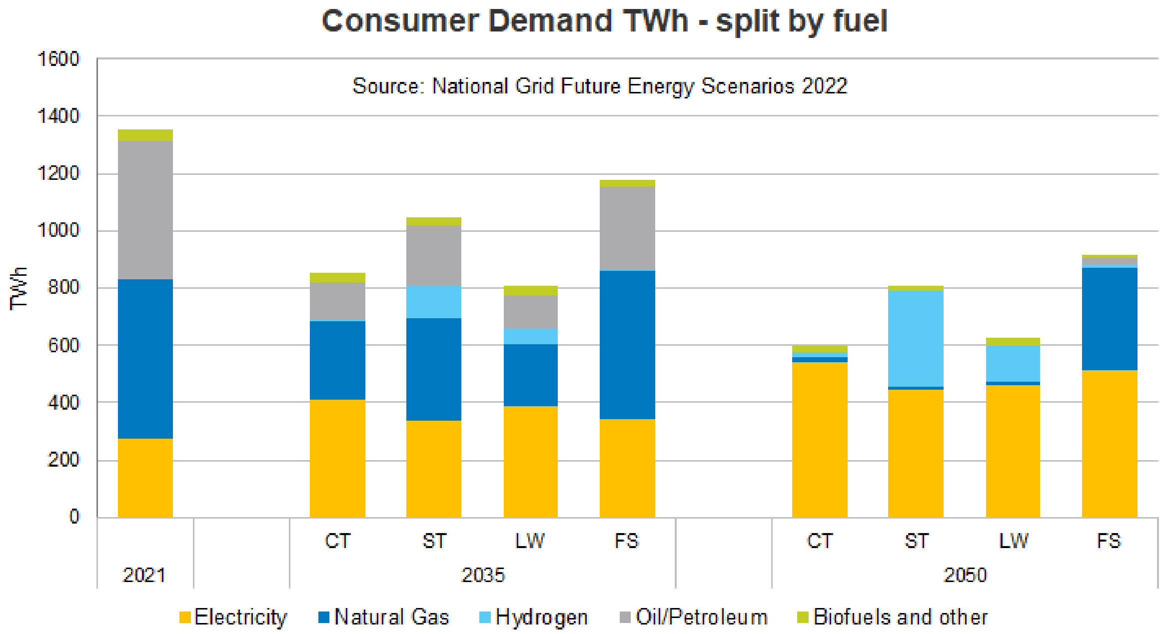


Industrial demand-side response is assumed to be very high. Yes, processes that use a lot of electricity can provide enormous amounts of DSR, but National Grid fails to realise that, beyond low levels of DSR, industry would have to stop in order to provide it. That involves employing people for overtime to do the work that they didn't do while they were being paid to be idle; it requires changing (not just once, but constantly) shift patterns including paying for additional shifts at premium cost, it disrupts output and requires large buffer stocks, and it greatly reduces maximum plant capacity. So such large industrial DSR is not economically practical.

Data Centre Demand

It is curious how demand for energy for data centres varies by so much per scenario: by 2050. 5TWh for FS, 10TWh for ST, 15TWhfor CT and 20TWh for LW; and over 80% of that demand will have materialised by 2035. Surely, the amount of data centre consumption depends on things other than energy scenarios, and should be similar. Therefore a single demand figure should be chosen. This variation distorts the demand curve for each scenario and, consequently, the supply mix. However the percentage effects of this error are small (<2%) in comparison with total annual demand.

Consumer Demand by Fuel Type



In conclusion to this analysis of consumers, National Grid forecasts the demand by fuel type as per this graph, which is shown differently for each of the four scenarios. Note that this includes the distortion for data centres, discussed briefly above.

They take demand as being the yellow bar at the bottom, which is a major error:

- Natural gas is unlikely to have such a large part to play, as CCS is impractical[7].
- Hydrogen will derive mostly from electrolysis, as again CCS is impractical.
- Oil / petroleum will have to be from synthetic fuels, derived from hydrogen.
- All electrolysis and synfuel production require lots of electricity, greatly increasing electricity demand – though substantial parts of it may be demand that is not seen by the grid as the conversion is done directly from renewables.
- Electrolysis hates intermittency, as does fuel synthesis, so suitably-scaled storage benefits electrolysis and fuel synthesis[8], and so needs inserting into the process. This has efficiency implications: the efficiency of storage reduces it, but the improvement in electrolysis / synthesis efficiency and equipment cost/life will greatly help.
- Therefore the total energy bar will be taller, and even most of the natural gas, hydrogen and oil/petroleum parts are provided by electricity.

Apart from that, the extent of demand reduction in all scenarios stretches credulity and sounds more like wishful thinking:

- Residential natural gas demand is transformed into electricity (heat pumps) at an assumed 5:1 efficiency improvement. This may be true, strictly, but to deliver the heat as required will require heat storage (high efficiency) where people

[7] https://www.storelectric.com/carbon-capture-use-and-storage-ccus-and-ccs/
[8] https://www.storelectric.com/wp-content/uploads/2022/07/Hydrogen-and-CAES.pdf

have sufficient space and electricity storage (lower efficiency) in the majority of homes and commercial premises where they don't. Therefore an efficiency factor needs inserting for storage.

- ST and LW scenarios have substantial hydrogen-fired boilers. While they conveniently re-use infrastructure and equipment from natural gas, the fuel will be much dearer in comparison with electricity, and therefore few will want to use it. Thermodynamically, it is a waste of hydrogen, one of the highest forms of energy, created laboriously with energy-intensive activities, to turn it into low-grade (i.e. not industrial temperatures) heat which is the lowest grade of energy. It's more efficient to avoid the intermediate step of electrolysis, and use the electricity directly in heat pumps.
- There appears to be no consideration of the fact that heat pump efficiency deteriorates with ambient temperature, falling to zero at about -8^{o}C. As that temperature is approached, there will be wholesale switch-over from heat pumps to direct electric heating. Although this is likely to be infrequent enough to have little effect on total annual demand, it is likely to provide a spike in demand during the highest demand periods of winter. Unless it is planned for, and generation, storage and grid capacity provided for it, households and businesses around the country will either go without heating or crash the grid.

Digitalisation and Markets

Digitalisation (if you'll excuse the poor grammar: it's a mistake coined in Brussels for digitisation) is put forward as a panacea. As well as grossly over-estimating its benefits (see above, *Prosumers, the Majority, and Aggregators*), it is seen as a very broad panacea. But digitisation only optimises the energy in the system, with limited movements in location and time; it does not create new energy. If there isn't enough, there just isn't enough – however well it's optimised.

"To deliver higher levels of flexibility, we need sharper market signals to incentivise the right outcomes." Correct. So why are the ministry, regulator and grid operators so focused on destroying market signals?

- The cost of electricity is an ever-decreasing ~20% share of the price of electricity[9] – wholesale costs are ~30%, but these are themselves made up of both generation costs and further levies and charges;
- Price caps on consumer bills reduce market signals;
- Promoting ever more extreme forms of DSR and V2G, and salami-slicing that incentivises narrowly capable plants like batteries, creams off the higher-value revenue streams that are needed to pay for longer-duration storage, and therefore increases total system costs because the longer-duration storage is still needed and so must put up its prices for what these other sources cannot provide;
- Short-duration contracts prevent new plants being built, as only sweated assets can compete.

[9] https://www.ofgem.gov.uk/energy-advice-households/costs-your-energy-bill

What the Digitalisation Strategy Addresses

The government's digitalisation strategy addresses the publication and exchange of data between the major players in the market, proposing to set standards for both publication amount and the structuring and formatting of such data to enable the players to exchange it. This is supposed to enable distributed resources to support system needs, such as Demand Side Response (DSR), Vehicle to Grid (V2G) and both trading and aggregation of distributed/domestic resources (which is part of DSR). In theory it will address issues such as getting the greatest benefits from SmartMeters (though doesn't address why they can only trade on half-hourly resolution) and trading/dispatching such resources.

What the Digitalisation Strategy Does Not Address

This strategy does not address matters such as:

- Trading energy: the strategy is about publishing and exchanging data, not about enabling digital trading;
- Ability to trade "energy plus", e.g. plus dispatchability, inertia etc.;
- Energy cost per transaction –
  - Varies from over 885kWh/transaction for Bitcoin and 102kWh/transaction for Etherium to 0.00017kWh/transaction for Hedera-based tokens,
  - "The growing energy consumption and associated carbon emission of Bitcoin mining could potentially undermine global sustainable efforts … the annual energy consumption of the Bitcoin blockchain in China is expected to peak in 2024 … this emission output would exceed the total annualized greenhouse gas emission output of the Czech Republic and Qatar" – ignoring all other currencies, and all other countries[10];
- Capacity of number and rate of transactions;
- Interoperability of different trading platforms;
- Ability of a single installation to trade seamlessly at multiple levels, e.g. a micro-grid trading both peer-to-peer and with the grid for Demand Side Response;
- Basing trading on energy and services provided, rather than on a currency –
  - The latter fluctuates in value with the value of the currency, providing enormous commercial risk, which needs offsetting by increasing prices, and some systems may contract for a certain value of energy which may deliver variable amounts of energy,
  - The former is a firm commitment as to what will be delivered to / purchased from the system/trader/provider;
- Ability for distributed creation of digital mirrors of physical capacity/capability –
  - Each plant will need to make its own capability available when it'll be available, and to withdraw capability for planned down-time,
  - Doing this centrally would be a huge, slow and unresponsive bureaucratic task that would limit the number (and hence lower limit of size) of transactions.

[10] https://www.nature.com/articles/s41467-021-22256-3

Transportation

Hydrogen Fuel Cell or Battery Vehicles?

"*We expect adoption of Battery Electric Vehicles (BEVs) to be the most common way to decarbonise cars and vans, with the role of hydrogen being less certain and varying across scenarios.*" In all scenarios, around 100TWh of battery electric vehicles (EVs) are expected by 2050. This is impossible: there is not enough lithium in the earth's crust, and there is even less of cobalt, nickel and rare-earth metals. Battery EVs also have a number of major problems, some of which have no technical fix and others whose fix would be prohibitively expensive.

These problems include:

1. **Grid Reinforcement:** All the EV chargers would require tripling (at least - maybe up to 6x reinforcement) of every single level of the grid from the domestic connection through to the transmission grid, and all transformers and substations in between.
   - And the rush hour (large numbers wanting to use and/or charge their vehicles at the same time) would have to be stopped.
2. **Charging:** 40% of homes (principally poorer ones) don't have any dedicated parking spaces, and more have insufficient for their vehicles:
   - People will not want to walk substantial distances to find their vehicles;
   - Centralised parking/charging would take enormous public investment, and require the construction of large centralised facilities;
   - Public and commercial charging will always be more expensive than domestic;
   - Vehicle-to-grid electricity storage (V2G) won't work when vehicles cannot be left permanently connected;
   - Shared mobility would increase mileage substantially owing to empty journeys;
   - All this would reinforce rather than reduce wealth discrepancies.
3. **Weight and Distance:** It's inappropriate for heavy vehicles (insufficient power density per unit weight and volume) or for more heavily used vehicles (long re-charging times), for both of which hydrogen / fuel cells are better:
   - Energy density of lithium-ion batteries is only 1% of that of petrol or diesel;
   - Re-fuelling hydrogen vehicles will take little longer than petrol or diesel, whereas re-fuelling electric vehicles takes much longer;
   - Fast-charging greatly reduces battery life and places enormous stress on the electricity system supplying the charger, in turn requiring yet more local storage – and refer back to resource insufficiency above.
4. **Efficiency:** there is great emphasis on the efficiency of batteries in vehicles, and none on the inefficiencies of batteries themselves[11]; while this link looks at grid-connected batteries (and therefore apply to charge-point connected

[11] https://www.storelectric.com/batteries-expensive-and-inadequate-solutions/

batteries), its considerations in fundamental efficiency and its lifetime deterioration remain valid for vehicles.

5. **Resource Sufficiency:** There isn't enough lithium in the earth's crust for all the vehicles of the world[12], even less cobalt and even less rare-earth metals. If the 40-60 gigafactories currently planned world-wide are built, they would exhaust the lithium deposits in all current and under-development fields in 2-10 years according to figures from The Economist[13]. Electrifying just British cars "would require production of just under two times the current total annual world cobalt production, nearly the entire world production of neodymium, three quarters the world's lithium production and at least half of the world's copper production" according to leading scientists[14]. And these comments all ignore:
    - Vans, buses and lorries;
    - Use of batteries in electricity systems, houses, portable and remote devices, or other applications such as aviation, shipping, rail etc.;
    - The short life and poor recyclability of batteries; or
    - Any of these considerations in any other country – there is sufficient lithium (ignoring the other metals, many of which are scarcer) for just 77% of cars world-wide[15], ignoring all other uses and considerations.

These are all dealt with in detail in the blog Electric Versus Fuel Cell Vehicles[16].

EV Efficiency

It appears that the V2G proposals assume 100% efficiency in V2G services, which will not be attainable: a perfectly new battery requiring no cooling yields ~96% efficiency, whereas one approaching its end-of-life yields ~75%, so a reasonable assumed average efficiency would be ~85%; then there are converter efficiencies – 90% is

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12 There is sufficient recoverable lithium in the world to power only 77% of vehicles by 2080, ignoring any use of lithium for the electricity sector (which uses three time as much energy as transportation, including gas as it will be replaced by both P2G and electrification), portable devices and other uses https://www.researchgate.net/publication/264854684_Lithium_Resources_and_Production_Critical_Assessment_and_Global_Projections.

13 https://www.economist.com/news/briefing/21726069-no-need-subsidies-higher-volumes-and-better-chemistry-are-causing-costs-plummet-after (noting that "vehicles" primarily means cars, not vans, buses or lorries) -

Vehicles, 2016	25 GWh	750,000 vehicles
Mid-range: 2040 Bloomberg	15,500 GWh	465,000,000 vehicles
2040 OPEC	5,000 GWh	150,000,000 vehicles
2040 ExxonMobil	3,000 GWh	90,000,000 vehicles
Total lithium, 2016	180,000	tonnes in one year
2040 Bloomberg	111,600,000	tonnes in one year, just for vehicles
2040 OPEC	36,000,000	tonnes in one year, just for vehicles
2040 ExxonMobil	21,600,000	tonnes in one year, just for vehicles
Total available lithium in planet	210,000,000	tonnes
Years' output: 2040 Bloomberg	1.9	years, just for vehicles

14 https://www.greencarcongress.com/2019/06/20190624-uk.html

15 https://www.mdpi.com/2075-163X/2/1/65/pdf

16 https://www.storelectric.com/electric-versus-fuel-cell-vehicles/

reasonable[17], which has to be applied twice – once for charging and once for discharging. The total round-trip efficiency is therefore 0.85 x 0.9 x 0.9 = 0.6885 or 69% round trip, or about the same as large-scale long-duration storage.

Efficiency also needs to be apply to fuel cell vehicles because of the inefficiencies of electrolysis (and other means of making hydrogen), the energy consumed in hydrogen distribution, and leakage/seepage at any point from hydrogen plant through distribution to fuelling and vehicles.

Vehicle to Grid

FES 2022 depends on 33-73GW combined Demand Side Response (DSR) and Vehicle to Grid (V2G) storage. However the assumptions and forecasts relating to this require some challenging, all of which would need to be answered for V2G storage services to be reliable; for example,

1. All the cars in most developed countries, if turned into EVs that are 100% used for grid-connected storage, would account for only a part of the storage needs – they consume similar amounts of energy to the entire electricity grid, with only a 2-4-hour range, only half of which at most (if the system works flawlessly) would be available to the grid. Therefore it lacks the duration to provide true back-up for renewables.
2. Where they charge from solar power (office, shopping), which is the proffered model, differs from where they would operate as grid-connected batteries, and nobody has proposed a cost-effective model for the financial flows.
3. Most people don't want their vehicles on less than half charge, which halves (or less) the energy/storage available.
4. The bulk of the need for the storage is in the evening, when vehicles' charge is lowest, yielding a grossly disproportionate multiplication of point 3.
5. To roll out cars-with-solar widely, a high proportion of the parking spaces in the country would have to be fitted with chargers – who would bear the cost of that?
6. Only a minority of vehicles will have dedicated charging, due to the number of homes without enough dedicated parking spaces for the number of vehicles they have.

Analysing this roughly,

- ♦ Vehicles will be at different states of charge, so assume 50% charged.
- ♦ Travelling capacity will need to remain in the vehicle, so halve that to 25%.
- ♦ Over its life, it loses ~20% of capacity, so average battery capacity is reduced by 10%, cutting the available amount to 22.5%.
- ♦ We can assume that no more than about ⅓ of such vehicles are left in personal parking spots attached to personal chargers overnight, so the capacity available to the grid is only ~7.5% of total EV battery capacity.
- ♦ Applying the 69% round trip efficiency, this drops to 5.2%.

[17] https://www.electronicdesign.com/power/understand-efficiency-ratings-choosing-ac-dc-supply graph

- A typical car battery has 50kWh capacity[18], and there are ~30 million on the road in the UK, so available storage capacity is 7.76GWh.

This looks good until it is compared with the need: after sunset on a windless winter evening the country today consumes ~42GW x 5 hours = 210GWh, forecast by National Grid[19] to double by 2050.

FES 2021 assumes that 45% of consumers engage in V2G services (p58) in Leading the Way; the above analysis shows a maximum reliable availability (the first four bullets) f one-sixth of that proportion, even assuming (very rashly, as shown above) that the same proportion of vehicles are electrified as is planned in FES 2021.

And don't forget that all this consumes battery life.

Therefore the benefits of load shifting (smart charging, i.e. changing the time at which batteries are charged, again only available for the minority of vehicles being charged in private spaces on dedicated chargers) is their greatest benefit to the grid, with V2G (the ability to put charge back into the grid) a secondary benefit confined to smoothing small peaks in demand.

Autonomous Vehicles

Previous FES documents have waxed lyrical about autonomous vehicles (AVs) reducing energy demand. It is a welcome improvement that they are not mentioned at all; however this is only a partial improvement because in fact they will actually increase energy consumption for transportation – and also congestion because, although there will be fewer vehicles in the country, a much higher proportion of them will be travelling at any given time.

Consider three people (A, B, C) going to work. With owned vehicles, that is 3 journeys; with AVs it is 6 – albeit not all of the same length. An AV takes A to work, then travels empty to B; then takes B, then travels empty to C; then takes C, then has to travel empty to where A is. Half of all movements are empty, meaning a doubling of movements, though optimisation algorithms will help ensure that these empty movements are minimised in distance between drop-off and pick-up.

An Optimal and Workable Mix

Large-scale long-duration storage is much more cost-effective than using EVs for either load shifting or V2G. The other draw-backs of EVs far outweigh any advantages for the majority of vehicles – the ⅔ which are heavier duty and/or more intensively used, which may account for over 90% of mileage driven.

Therefore EVs are best suited for short-distance light-use applications.

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18 Example car battery sizes: Tesla Model S 75D is 75kWh; BMW i3 = 42kWh, Nissan Leaf = 40kWh, VW e-Golf = 36kWh, Ford Focus Electric = 33.5kWh

19 [Future Energy Scenarios 2020](#)

And both money and effort need to be devoted to developing and commercialising non-PEM electrolysis technologies, and rolling out hydrogen fuelling points to filling stations everywhere.

Independent analyses of battery versus hydrogen-fuel-cell EVs are available[20].

Rail, Aviation and Shipping

Decarbonisation of these sectors is discussed (p78) only in relation to emissions. There is no recognition that the processes of creating the synthetic fuels will require renewable energy, which is therefore not accounted for in any of the scenarios.

[20] E.g. https://www.lexology.com/library/detail.aspx?g=1bf1cbf0-ac2f-4b39-a3de-2df77a9a515e and https://www.motorbiscuit.com/hydrogen-fuel-cells-vs-batteries/

Whole Energy System

Electricity Supply Overview

The analysis is equally deficient in its analysis of electricity supply: it

- Relies on electricity imports during "times of system stress" (high demand and/or low renewable generation) when most of our neighbours are doing the same concurrently and won't have a surplus to share;
- Assumes nameplate capacity of all generation (baseload, dispatchable and intermittent), interconnectors and storage;
- Takes output rating of storage regardless of duration, when shorter-duration (sub-4-hour) storage would be exhausted well before the end of an evening peak during times of system stress;
- Over-states distributed and digital solutions' benefits, which merely redistribute the energy in the system, without ensuring that there is sufficient at all times;
- Does not appear to give full consideration of all aspects of biomass energy;
- Fails to apply a supply margin, whereas grids world-wide consider a margin of 10-15% above peak worst-forecast demand to be a minimum acceptable;
- Therefore under-states the need for storage in general and large-scale, long-duration storage in particular.

Consequences

The result of such predictions, and of regulatory directions, about which Storelectric has repeatedly warned, has been the black-outs of 9th August 2019, numerous near-misses in 2020 and 2021 to date, rocketing costs and complexity of balancing, stability and ancillary services, and a strategy to move faster and further down the same dead end.

The principal views and actions of government, regulator and grid operators have 10-year horizons, and are based on responding to demand. These two factors alone guarantee that the energy transition targets will be missed, and the energy transition itself will be unaffordably expensive and disruptive.

Costs of the Current Strategy

Referring to previous Storelectric studies, the current strategy costs:

- Over £1.75bn one-off plus £175m p.a. unnecessary grid reinforcement[21], and additional (not evaluated) cost of balancing and stability, **per GW** additional wind generation;
- ~£4bn excess BSUoS[22] charges (roughly, the cost of interventions by the Control Room, or non-energy costs of running the system day-to-day) in 2020-21 versus 2018-19, rising exponentially since intermittent renewables passed 16% of energy supplies[23];

[21] https://www.storelectric.com/saving-billions-on-grid-upgrades/
[22] BSUoS = Balancing Services Use of System; the costs of the network itself are recovered in a different charge, TNUoS = Transmission Network Use of System.
[23] https://www.storelectric.com/challenges-of-the-electricity-transition/

- Excess reliance on batteries[24], of which many are needed to deliver the same services as same-sized large-scale long-duration inertial storage like ours, and moreover, for which there is insufficient elementary lithium, cobalt and rare-earth metals in the earth's crust – ignoring how much smaller a proportion of which is exploitable;
- Excess reliance on imports through interconnectors[25], which not only will not be available (see above), but also our neighbours will have a political imperative to cut us off during times of system stress;
- Excess costs and difficulty of building and integrating renewable generation[26];
- £328m for 6 years' synchronous compensation 2020-26[27] that would be much cheaper if procured from inertial storage with suitable cost-saving revenue stacks;
- Complete under-estimate of the need for storage[28], with
- Excess reliance on Vehicle to Grid (V2G) and shared mobility[29].
- In short, it subscribes to most of the fads and fallacies of the energy transition[30].

Energy Flows

The energy flow projections (p106) show a number of concerning features, such as:

1. Inadequate storage (see separate section below);
2. No losses from electricity storage –
    - Losses should range from 30% to 50% depending on the technology,
    - These losses should be grid-to-grid lifetime-average, which would put batteries to the lower (i.e. greater losses) end of that range;
3. Inadequate electrolysis –
    - None at all for vehicles,
    - No conversion losses to synthetic fuels, e.g for aviation (complex hydrocarbons) or shipping (ammonia, or possibly methanol);
4. Inadequate storage of hydrogen which, elsewhere in the report, is considered to provide seasonal storage –
    - Inter-year storage is not considered, although year-on-year variation in renewable generation can vary by as much as 10-15%;
5. Inadequate losses from electrolysis –
    - Electrolysis is considered to derive largely from renewables,
    - Electrolysis does not perform well with intermittent power supply, so storage is needed to level it out[31];
6. Negligible losses from CCUS –
    - CCS with just 80% capture rate imposes a 25-45% inefficiency on any power station to which it's attached – and that's the theoretical losses: Boundary

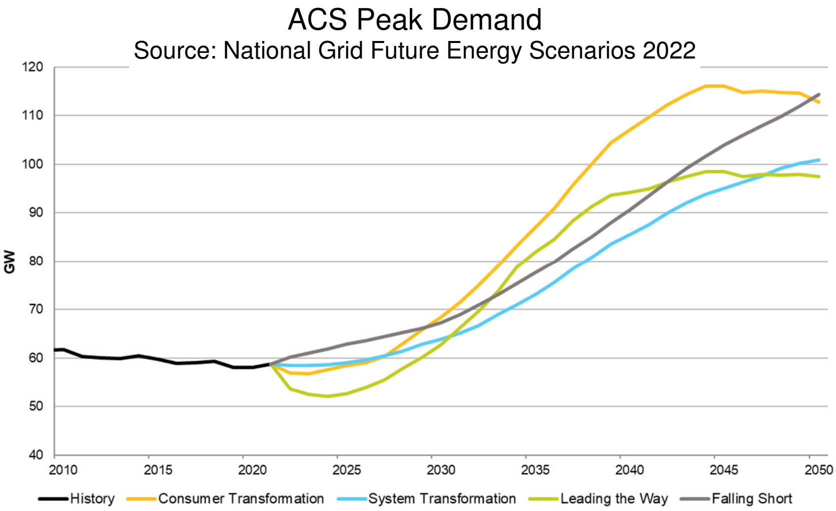
[24] https://www.storelectric.com/batteries-expensive-and-inadequate-solutions/
[25] https://www.storelectric.com/interconnectors-and-imports/
[26] https://www.storelectric.com/enabling-renewables-to-power-grids-affordably-reliably-and-resiliently/
[27] https://www.current-news.co.uk/news/national-grid-eso-claims-world-first-approach-to-inertia-awarding-328m-in-contracts
[28] https://www.storelectric.com/calculating-the-need-for-storage/
[29] https://www.storelectric.com/vehicle-to-grid-and-shared-mobility/
[30] https://www.storelectric.com/fads-and-fallacies-of-the-energy-transition/
[31] https://www.storelectric.com/wp-content/uploads/2022/07/Hydrogen-and-CAES.pdf

Dam is the only large power station with CCS, and its losses are worse for much lower capture rate,

- No allowance of energy consumption for transportation, compression and storage of CO2;
- Zero leakage rate assumed – though compare with global leakage rates of natural gas which are currently huge[32] but unquantified[33] globally, with Russia being the worst emitter[34] but America Permian Basin leaking 1.4%[35] of all methane produced.

7. No losses from methane reforming;
8. No CCUS in methane reforming, with consequent inefficiencies and losses (see CCUS with generation, above);
9. Excessive biomass, despite the lessons from Ukraine in which global food shortages are created at least in part due to the use of crops in biomass – in amounts that exceed the losses of Ukrainian grain for food[36].

Peak Demand

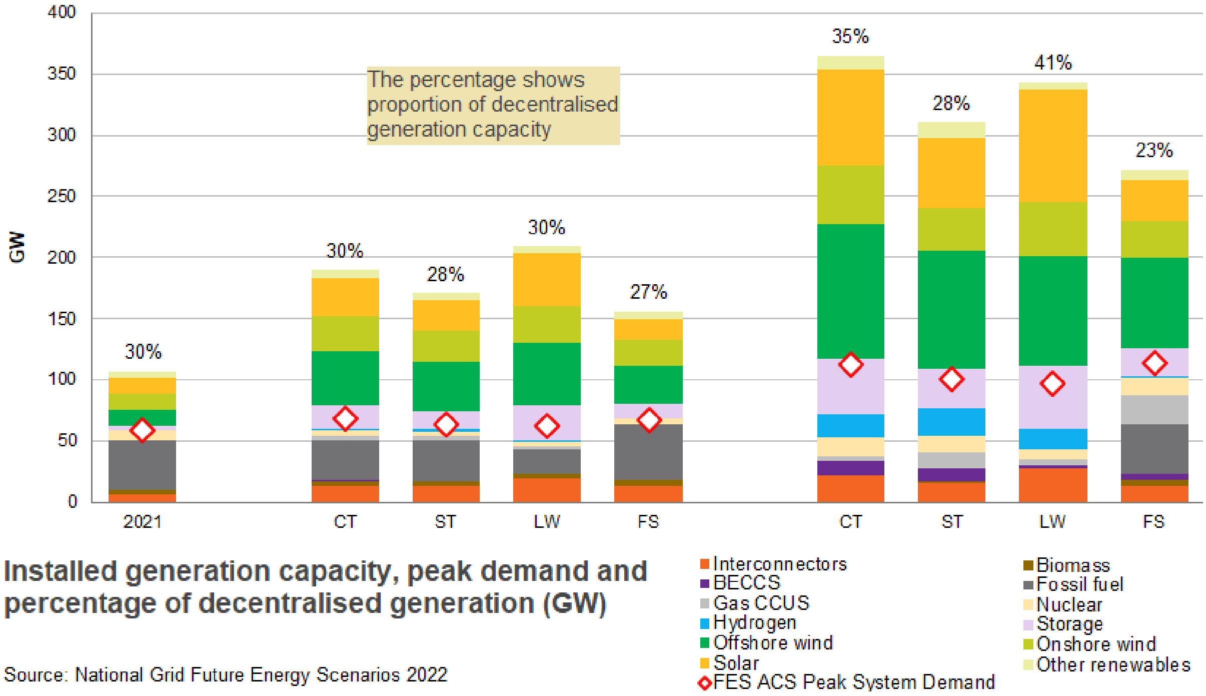


Peak demand is increasingly realistic, now approaching twice current peak demand; many independent forecasters predict that, with the energy transition of heating, transportation, industry and other sectors, it will be tripled.

A Recipe for Widespread and Frequent Black-Outs

The mix of generation envisaged by National Grid in 2030 and 2050 is:

32 https://www.newscientist.com/article/2306715-satellite-images-show-biggest-methane-leaks-come-from-russia-and-us/
33 https://www.bloomberg.com/features/2022-methane-leaks-natural-gas-energy-emissions-data/
34 https://www.bloomberg.com/news/articles/2021-06-18/gazprom-admits-to-massive-methane-leaks#xj4y7vzkg
35 https://earth.stanford.edu/news/methane-leaks-are-far-worse-estimates-least-new-mexico-theres-hope#gs.707wpi
36 https://www.economist.com/graphic-detail/2022/06/23/most-of-the-worlds-grain-is-not-eaten-by-humans



Installed generation capacity, peak demand and percentage of decentralised generation (GW)

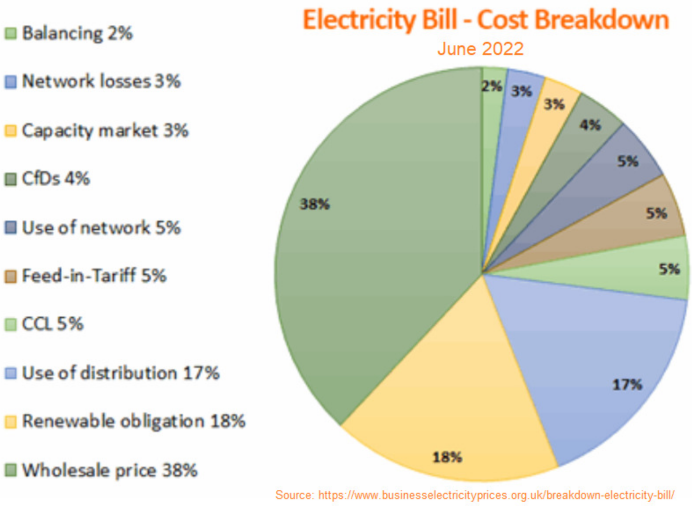
Source: National Grid Future Energy Scenarios 2022

This is a recipe for disaster, i.e. widespread and frequent black-outs:

1. Every scenario, over the entire period, relies on imports through interconnectors for actual electricity demand. They cannot be relied upon[37], as the Ukraine crisis proved: when our neighbours were short of (first) gas (then) electricity, they stopped flows into the UK and the interconnectors actually reversed their flows, leading to the UK having to engage in further multi-year contracts with coal-fired power stations.
2. Gas CCUS is expensive and impractical.
3. Gas CCUS would require much more BECCS to offset (a) the inefficiencies of carbon capture in the power station and (b) emissions in the mining, refining and transportation of the gas.
4. If hydrogen is used for security of supply, then enough power station capacity is needed to replace all other insecure capacity: mostly interconnectors and intermittent generation.
5. The storage cited is all one "lump", in which case it all needs to be large-scale, long-duration; otherwise on a windless winter evening it would be exhausted by 6pm.
6. Having such high volumes of interconnectors, batteries, intermittent generation and decentralised (distribution-connected, or distributed) generation would need fantastic amounts of curtailment and payment for naturally inertial plants to run throughout the year in order to provide some semblance of grid stability and resilience.
7. Such high percentages of distributed generation would add huge costs to the system: nearly all distributed systems rely on the grid for back-up, so the grid needs enough dispatchable capacity at all times to provide that back-up.

[37] https://www.storelectric.com/interconnectors-and-imports/

- This means that above a certain level (to be determined), any distributed generation merely adds costs to the system: it would cannibalise the revenue streams of the transmission-connected generation which would then have to raise its prices to achieve economic viability.
- This kind of cost increase is done all the time by National Grid, claiming that for services A, B and C they are procuring at best prices while other plants have to put up the prices of services X, Y and Z to compensate for the lost revenues.
- This is why the cost of generating electricity is only about 20-25% of the electricity price, down from 75-80% a decade ago. In the pie chart[38], note that the wholesale price of electricity itself includes ~50% charges and levies on generation.



A Statistical Approach to Forecasting

Part of the problem is the grid's statistical approach to forecasting. Two aspects of this are their use of de-rating factors and of dispatch models for medium- and long-term forecasting.

[38] https://www.businesselectricityprices.org.uk/breakdown-electricity-bill/

Technology	Generic ALF
Biomass	49.5396%
CCGT_CHP	51.0635%
Coal	20.3859%
Gas_Oil	0.4602%
Hydro	41.8887%
Nuclear	75.8434%
Offshore_Wind	49.4981%
Onshore_Wind	36.0719%
Pumped_Storage	9.7926%
Tidal*	23.1000%
Wave*	2.9000%
Solar*	10.8000%

Source: National Grid ESO, figures for 2021-22

De-rating factors[39] are assumed to be the output that a plant provides. They are not: they're an average between when it's producing 100% and when it's producing reduced amounts or nothing at all. When plants are all dispatchable, that difference doesn't matter. When most are intermittent, they can all fail at the same time, such as a windless winter evening – and, because such weather patterns cross frontiers, our neighbours will often be suffering the same shortfall at the same time, further increasing the problem of averages.

For different types of storage, the factors apply from the table below:

Name for technology class	Plant Types Included	De-rating factor (ECR 2018)
Storage by duration in hours for T-1 and T-4 auctions[26]	Conversion of imported electricity into a form of energy which can be stored and the re-conversion of the stored energy into electrical energy. Includes hydro Generating Units which form part of a Storage Facility (pumped storage), compressed air and battery storage technologies.	Dura'n: T-1: T-4: 0.5hrs 17.50% 14.91% 1.0hrs 34.21% 29.40% 1.5hrs 50.00% 43.57% 2.0hrs 62.80% 56.68% 2.5hrs 71.96% 66.82% 3.0hrs 78.09% 73.76% 3.5hrs 81.57% 77.78% 4.0hrs 95.52% 80.00% 4.5+hrs 95.52% 95.52%
DSR[27]		84.28%

nationalgridESO | Electricity Market Reform Delivery Body

From the same report, the de-rating factors for interconnectors are:

39 https://www.emrdeliverybody.com/CM/Capacity.aspx

Table 10: Simulation results: 2022/23 imports as percentage of interconnector capacity

	FES							Stress 5%					
Country	Historical	Average	BC	CR	TD	SP	CE	Average	BC	CR	TD	SP	CE
Ireland	5	30	42	26	24	26	30	33	36	31	30	31	37
France	55	78	59	77	81	85	86	75	68	73	77	79	77
Belgium	67	56	36	55	57	67	65	42	35	39	43	44	49
Netherlands	70	47	27	41	45	62	57	34	28	31	33	39	40
Norway	96	98	100	98	98	98		92	92	93	93	90	

Interestingly, despite large amounts of fossil fuelled generation still remaining on the continent, the "stress 5% figures" (i.e. those during times of system stress) are all (except Ireland, which is a net demand during peak times) reduced compared with the average. This is a harbinger of us not being able to rely on them at all in future. The grid's fundamental duty is to provide sufficient electricity to meet at all times, so all capacities must be planned around the most stressed times unless blackouts will be tolerated.

Therefore any calculation of sufficiency of supply using nameplate capacities will yield inadequate results. Applying these figures to the above supply and demand table would yield even more worrying results.

Dispatch models are excellent for looking at the grid today and in the near future. But National Grid, Ofgem and BEIS use them for the medium- and longer-term future too, where they break down. Every step into the future requires assumptions and educated guesses; the further into the future, the more important these are as a proportion of the whole. By about 5 or 10 years hence, the result is no longer credible. Instead, other means need to be found to establish the needs of the grid over such periods of time – methods such as Calculating the Need for Storage, below.

Carbon Capture, Use and Storage (CCUS) and CCS

The natural gas strategy all depends on Carbon Capture, (Use and) Storage, or CCS / CCUS.

Usage of captured carbon is at a very early stage of development, with some promising lines of development – however these are all at very early (mostly theoretical and laboratory) stages. And most of them result in the re-emission of the CO_2 later on because it's put into products such as synthetic fuels which are later burned, and plastics which is later thrown away. The UK parliament has released a briefing on this[40]. Therefore usage does not carry promise of major CO_2 emissions reduction in the near future, so the principal target for national emissions reduction must remain CCS. And usage means are currently prohibitively expensive, though future developments may solve that challenge.

[40] https://researchbriefings.parliament.uk/ResearchBriefing/Summary/POST-PB-0030 ("CCC Report")

CCS is expensive and imposes inefficiencies on the host system, e.g. the power station. It is also not 100% effective (though the unstated assumption throughout is that it is 100% effective) and both costs and resultant inefficiencies rise exponentially as the percentage of carbon captured rises. For example, CCS increases coal burn by a quarter for the same power output[41], raising its levelised cost of energy to well above that of other generation technologies[42]. A well-financed Canadian project at Boundary Dam[43] found that CS imposed 40% inefficiencies on the power station while only capturing 90% of the CO_2 emissions. It is notable that increasing capture rates increases capital and operational costs and imposes greater inefficiencies on the host plant.

But the most neglected element of CCUS is its hazardous nature. It captures, transports and stores for millions of years a gas which is colourless, odourless, poisonous and heavier than air: any leakage (such as from an earth tremor or equipment failure) would cause an asphyxiating cloud which would roll over the ground wherever a light wind blows it, including over population centres, much like a World War 1 gas attack. Making large networks safe in decentralised installations would be virtually impossible, so it must be concentrated in clusters.

Emissions cannot be avoided in certain industrial processes such as the cracking of limestone ($CaCO_3$) into lime (CaO) for cement[44]: chemically, $CaCO_3 \Rightarrow CaO + CO_2$. CCS is necessary for such processes. But it is not necessary for power generation: renewables plus large-scale long-duration storage such as Storelectric's is cheaper, more efficient and more environmentally friendly. Even nuclear is cheaper than gas plus CCS. There may be benefits in building a few CCS power stations that piggy-pack on industrial CCS clusters, but elsewhere it is neither affordable nor sensible.

For such reasons, the Americans cancelled many projects before construction, such as the Kemper coal gasification and CCS project when its capital cost for a 582MW plant exceeded $7.5bn[45], i.e. $12.9bn/GW. If the Americans can't get it up and running despite paying considerably more than Hinkley Point (which is £20bn for 3.2GW, i.e. £6.25bn/GW or $8.4bn/GW), then what hope do we have of doing so?

Integrated Thinking

While claiming to address the whole energy system, there is very little in the structure, control and operating frameworks within the system that actually does so, for example:

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[41] http://www.world-nuclear.org/information-library/energy-and-the-environment/clean-coal-technologies.aspx (see table 1)

[42] For American LCOE costs (UK ones are higher), see table 1b (p8): LCOE for CCS coal is $132.2 - $140 https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf

[43] https://www.saskpower.com/Our-Power-Future/Infrastructure-Projects/Carbon-Capture-and-Storage/Boundary-Dam-Carbon-Capture-Project

[44] This chemical reaction alone accounts for >4% of global emissions, over half of the total emissions (8%) from cement manufacturing, most of the rest being from heat input to the process: https://www.bbc.co.uk/news/science-environment-46455844

[45] https://en.wikipedia.org/wiki/Kemper_Project and https://www.smithsonianmag.com/smart-news/major-clean-coal-project-mississippi-shut-down-180963898/

- Proposals that benefit the physical grid, contract prices, system operability / controllability, offshore networks (OFTOs) and renewable generation cannot happen because there are no mechanisms for:
  - Putting all interested parties together to discuss the proposals, its costs and its benefits,
  - Modelling and evaluating it, with input from all parties,
  - Sharing the benefits with the project developers / operators,
  - Establishing joined-up or coordinated contracts;
- Technologies that must necessarily deliver more than one contract type concurrently (see Revenue Stacking and Salami Slicing[46]);
- Providing contracts of a length that correlates with plant life and roles, e.g.
  - Sufficiently long[47] to encourage new build (most is done with special financial instruments that distort and mute markets, but have 15+-year durations),
  - If non-grid solutions are implemented to benefit grids (e.g. storage to reduce grid connection and reinforcement), it cannot be removed from the system at the end of the contract without multi-£billion investment to reinforce both grid and connections, so such contracts must be life-of-plant duration, exactly analogous to the physical grid which it's replacing.

Forward Thinking

There is little forward view: 10 years is totally insufficient. The lead times to construct both grid and also many assets such as large-scale long-duration storage, are such that a 10-year view would yield totally insufficient investment to achieve Net Zero.

The current policy of maximising asset utilisation (which is, more accurately, "sweating assets") has led to a system in which most of the grid, at both transmission and distribution level, is both modelled on the 1950s-1970s economy (they don't seem to have notice that the economy's and country's structure have changed in the last 50-70 years) and almost totally saturated, unable to take significant new assets without major grid investment. Both the cost and lead time of such grid investment prohibit many very beneficial proposals being brought forward, greatly impeding both the energy transition and the adaptation of the system to modern patterns of supply and demand.

The purpose of the current policy is to reduce costs by not "gold-plating" the grid, which was always a mythical concept. Building grid to plan instead of reacting to demand can be up to ⅔ cheaper, as evaluated in South Australia (the Energy Networks Association has the details), and provides a more adapted and resilient grid. The argument that unnecessary assets end up being built is wrong, because (a) the savings are so great that any surplus construction merely dents the benefits, and (b) eventually all the assets will be used, which is what has happened with the current grid that has been so mis-represented as "gold-plated". It's only because long-term needs

46 https://www.storelectric.com/wp-content/uploads/2021/08/Revenue-Stacking-and-Salami-Slicing.pdf

47 https://www.storelectric.com/issues-with-ever-shortening-contract-durations/

were prioritised that we have a grid at all, and that the grid was built robust enough to cope with the last 30-40 years' underinvestment due to current policies.

Quantifying the Challenge and Hoping for the Best

"Net zero will only be possible if we start implementing measures now. We can't wait until 2050" (p39, FES 2021). Very true, but under current regulations, the appropriate amount, scale, durations and capabilities of technologies enabling the energy transition will not be built. Quantifying the challenge and hoping for the best will not work. Two prime examples are:

1. National Grid complained recently that they had been showing multi-million-pound constraint costs around the Scottish borderland, yet no projects had been proposed to alleviate it. That is because of current regulations and contract terms.
2. Large-scale electricity storage: National Grid have been forecasting a need for tens of GW of storage, a substantial proportion large-scale, yet no such plant has been started. The nearest to it is the Highview demonstrator, which is only happening because of tens of millions of pounds worth of government innovation funding. Until the right regulations and contract terms are in place, including incentivisation for first-of-a-kind plants (this applies to any technology), they will not be built.

Unless and until there are contracts of appropriate durations[48], there is no guarantee that assets built against demonstrated need will continue to be needed: National Grid may undertake some other work that ruins their business case.

Unless and until there are suitably broad contracts[49] for a plant's capabilities, there will remain potential for a plant to become legally and/or commercially un-viable at some point – especially broadly-capable and large-scale plants of any type.

Unless and until there is a suitable regulatory system[50] that incentivises all that the grid needs, and lets contracts accordingly, there will have to be ever-increasing and ever-costlier interventions to get the right services – and, like all centrally-planned systems, it will be far inferior to a truly market-based one.

Unless and until storage has its own regulatory definition[51] and regulatory provisions, as storage and not as a sub-set of generation, based on the definition and regulatory provisions of interconnectors or substations (which are also grid services that don't generate any new electricity), to level the regulatory playing-field, then the British electricity industry will never build enough, and always be dependent on uncertain

[48] https://www.storelectric.com/wp-content/uploads/2021/03/Issues-with-Ever-Shortening-Contract-Durations.pdf
[49] https://www.storelectric.com/wp-content/uploads/2021/08/Revenue-Stacking-and-Salami-Slicing.pdf
[50] https://www.storelectric.com/wp-content/uploads/2021/05/A-21st-century-electricity-system.pdf
[51] https://www.storelectric.com/wp-content/uploads/2021/03/Regulatory-Definition-of-Storage.pdf

imports during times of system stress[52] from overseas generation subsidised by the British energy system.

The scenarios all have the rosy prediction of net-exporting by 2040. This will not happen without the above changes. In fact, all that has gone wrong with the energy system is due to the lack of such basic easily developed and implemented solutions. And if quantifying the challenge and hoping for the best will not work, this is especially true when the quantification is wrong, as we will see below.

Network Challenges of the Energy Transition

The energy transition has many challenges of its own[53]. It is largely (but not wholly) about replacing rotational turbine-based generation with renewables.

- Turbines are dispatchable, meaning that we can vary their output on demand; renewables are mostly intermittent, meaning that they're available in certain weather or times of day. So the first part of the challenge is turning intermittency into dispatchability. That's about time-shifting energy, which means storing it when we have surplus for use when we have need.
- Turbines are rotational: they spin with real inertia, which provides grid stability and which is the basis of a number of other grid stability services.
- Turbines also produce other benefits such as reactive power and reactive load, to keep the system working smoothly.

Renewable generation's intermittency means that their grid connections need to be sized for peak output, not average output or demand, so in March 2021 National Grid put out their Network Options Analysis that said they have to invest almost a billion pounds in network reinforcement for every gigawatt of offshore wind that we're going to connect until 2025 – and those being connected after that date will cost increasingly more. In July 2022 they increased that to £1.37bn per GW. Adding the costs of connecting up balancing and ancillary services, it is reasonable to expect that each new GW electricity will require £1.75bn grid reinforcement.

But this is not all: operation and maintenance (5% of this, every year) and amortisation (another 5% p.a.), it also costs £175m p.a. to maintain the additional grid for each new GW of renewable electricity.

We can avoid many of those billions of pounds-worth of expenditure, and the eyesore grid they'd have to build.

Short Termism and its Problems

The regional analyses show that "the largest demands today are in the big cities, and particularly the south of England", yet the last four decades' focus on the short term have ensured that the grid is largely as it was designed for the British economy in the 1950s.

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52 https://www.storelectric.com/wp-content/uploads/2021/03/Interconnectors-and-Imports.pdf
53 For a fuller treatment, see https://www.storelectric.com/challenges-of-the-electricity-transition/

The entire process of planning and regulating the grid is exceedingly short-term. The longest vision, NG's Network Options Assessment, focuses on a 10-year timescale; with such thinking, the grid would never have been built in the first place, leaving the entire economy struggling and held back. More recently National Grid has produced a report Pathway to 2030: Holistic Network Design[54] – yet 2030 is only 7.5 years away. An example of such short-termism was the much-touted (though, thankfully, not achieved) "second dash for gas" to achieve 2025 emissions targets even though 2030 emissions targets would have turned most such power stations into stranded assets. The only way to avoid such waste is to prioritise 30- and 50-year timeframes – which will ensure a cheaper, more reliable and more resilient grid in those timescales without increasing greatly the cost to today's system/consumer.

As most grid-connected assets that are developed today will still be operational in 2050, all new developments must be one of:

- 2050 compliant (i.e. emissions-free);
- Convertible to 2050 compliant; or
- Short-life assets that will be replaced before emissions targets exclude them from markets.

If short-life assets, emissions relating to disposal and replacement should be taken into account, as should global resource availability in comparison with forecast global demand, e.g. lithium, cobalt and rare-earth metals.

Proactive Grid Development

It is worth recalling that the grid was only built because of whole-system, long-term thinking. For that reason, it was developed and extended based on forecast rather than current needs. This has been caricatured politically as "gold-plating the grid", with a focus over the last decades on increasing utilisation. But in reality,

- Building the grid in a measured and rational programme ahead of need is as much as two-thirds cheaper than building it reactively against need, as discovered in Australia; the Electricity Networks Association can cite excellent examples from South Australia and elsewhere, to support this statement.
- Even if such demand did not materialise at the expected time, it has materialised since, so the benefits of investing in such more rational and measured ways greatly outweigh the small number of years for which a given part of the grid was under-utilised.
- And the current method means that now there are large and unknowable numbers of projects that are just not being proposed because of the cost of reinforcing the grid to accommodate them, slowing down the energy transition and reducing the quality of the entire system.

[54] https://www.nationalgrideso.com/future-energy/the-pathway-2030-holistic-network-design

Excessive Costs for Consumers

The result of all this is that system costs are rising so fast that a pro-market government has instructed a market regulator to intervene in the free operation of markets by imposing a cap on consumer electricity prices.

The poor design of market mechanisms means that all manner of levies and charges are added to electricity bills. A couple of decades ago, these totalled under 25% of consumers' bills, paying for grid upkeep, and balancing and ancillary services. Now they account for over 50% and still rising inexorably. This in turn means that plants are deriving a majority of their revenues from activities other than providing energy and the services necessary to maintain the grid, distorting market price signals; the price cap distorts them further.

Hydrogen

Uses of Hydrogen

Hydrogen is envisaged mainly for combustion in turbines to produce dispatchable and reserve electricity, the provision of high-intensity heat and heavy transportation. This omits its main uses, all cited above, of:

- Reducing agent in iron and steel making, and comparable industries;
- Feedstock for the creation of synthetic fuels and complex chemicals such as ammonia, methanol and complex hydrocarbons;
- Chemical industry, especially in new chemical pathways that avoid or reduce emissions;
- Feedstock / precursor chemicals for other clean fuels;
- Light transportation;
- Non-transportation uses of fuel cells.

While transportation use is included in FES' analysis of transportation, it is included at much too low a market penetration – see *Transportation*, above. Combustion in turbines is too costly and inefficient (whole-cycle) to displace large-scale long-duration electricity storage. All in all, the expected amount of hydrogen is under-estimated.

Using hydrogen to balance intermittent generation is not practical:

1. Electrolysis and fuel synthesis (including methane reformation) hate intermittency, which reduces both efficiency and plant life;
2. Many times more electrolysers (and synthesis plants) are needed for the same output if they are only producing intermittently – and such plant is very expensive;
3. It doesn't balance the "variable demand" side of the equation, as electricity storage does – unless it's then combusted, for which see below.

Hydrogen Networks

With so many of these chemical and industrial plants, and hydrogen fuelling stations, being distributed around the country, this would require conversion of the natural gas grid to hydrogen. But since all of these applications require very or fairly pure hydrogen, there is no benefit at all in having blended natural gas and hydrogen in the network. The only feasible use for such mixtures is to feed into boilers during a transitional period for avoiding the need to change such boilers wholesale, especially if a large proportion are hydrogen-ready. But electric heating (especially with heat pumps) is cheaper, and blended gas in the system would prevent the development of a network of industries and fuel stations, thereby impeding the roll-out of hydrogen consuming technologies, so impeding the energy transition as a whole. Moreover, adjusting the gas-consuming equipment would be very expensive as multiple adjustments and purchases would have to be made as the hydrogen percentage is increased gradually: in general terms the flame size, shape and temperature are different, and 50% more gas volume is used for the same energy output.

The best way to roll out hydrogen would be to base initial usage locations on the towns near the seven hydrogen hubs currently being developed. These would be 100% hydrogen – a single conversion. As more hydrogen becomes available, these hydrogen grids would be expanded to neighbouring areas until eventually they merge.

Apart from very specific applications (e.g. fuel tanks), transportation outside pipe networks is very difficult and expensive as hydrogen is so light. One lorry can carry 3 tonnes of compressed hydrogen. To carry more, it would have to be maintained at cryogenic temperatures below -252.9 °C, its boiling point (or slightly warmer if pressurised). Therefore it is likely that non-piped transportation would be done in other forms, such as ammonia or methanol; this implies that conversion into complex chemicals is likely to be done on the same pipe network as hydrogen production.

Hydrogen Power Stations

Combusting hydrogen in turbines is, at ~60%, (theoretically) almost as efficient as burning natural gas. But this does not take into account the inefficiencies of electrolysis (or other means of producing hydrogen) and transportation. The theoretical best efficiency of the cycle renewable generation to electrolysis to transportation to combustion in a turbine to electricity on the grid is in the low 40s %. Mid-thirties % is realistically achievable; today it's at the mid-20s %. And the total capital cost is higher than that of 70% efficient adiabatic CAES, and even of 75% efficient pumped hydro.

Therefore the only justification for hydrogen power stations is energy security, for seasonal or annual fluctuations. But this envisages having sufficient hydrogen power stations, and stored hydrogen, to power the entire grid for long periods of time – and which is very rarely used. That envisages fantastic expense for reserve capacity, which the energy system hitherto has never afforded, and is never likely to afford.

Hydrogen Production – Electrolysis

Hydrogen production by electrolysis ("green hydrogen") is envisaged "to maximise the use of renewable electricity generation", levelling the intermittency of generation and also producing during periods of congestion. This is true but highly uneconomic and, even so, only addresses half of the challenge.

It is highly uneconomic because 6-8 times as much electrolysis capacity per unit of output hydrogen is needed if its in-feed electricity is solar, as compared with baseload input. For offshore wind the multiple is 2.5-3, for onshore wind it is 4-5. All of these are uneconomic in both capital and operational costs, as compared with using large-scale long-duration storage to deliver near-baseload energy to the electrolysis plant. Near-baseload requires ~6-12 hours' duration; true baseload would require ~2 weeks' duration (336 hours); so the optimum will be an economic balance of the cost of increasing storage duration intersecting with the decreasing cost of electrolysis.
All projections of electrolysis are based on the two main technologies in use currently: Proton Exchange Membrane (PEM) and Alkali. Both are very expensive in both capital and operational costs as both the membrane and the alkali are consumables. PEM is safer but necessarily low-volume; scale-up requires hundreds or thousands of cells.

Alkali is intrinsically larger-scale but with big health, safety and cost issues in procuring and handling the alkali and disposing of the waste.

Instead, new high-volume electrolysis processes need to be developed. A number of these have been proposed in the past, but not funded – mainly due to funding ministries' innate conservatism. Among these technologies, Storelectric has patented[55] using the heat of compression to catalyse electrolysis; this will be developed when the company has sufficient revenues from its CAES to fund and resource it.

Hydrogen Production – Methane Reformation

Otherwise known as Grey, Black or Brown hydrogen, Steam Methane Reformation (SMR) is the principal way in which FES 2021 envisages hydrogen to be produced in the System Transformation scenario, with it being a substantial minority in Consumer Transformation. Essentially methane is broken into hydrogen and CO2 by a chemical reaction with steam: $CH_4 + 2H_2O = 2H_2 + CO_2$.

This process is already too expensive to substitute methane economically, without CCS. With CCS ("blue hydrogen"), plant efficiency will drop and, although CO_2 capture will be cheaper owing to the higher concentrations, both expensive and less than perfect (See *Carbon Capture, Use and Storage (CCUS) and CCS*, above). This in turn will require negative-emissions installations such as DACCS (Direct Air CCS) and BECCS (Bio-Energy with CCS), adding further costs and inefficiencies to the whole system.

Transition to Hydrogen

It is good that the natural gas network is planned to be re-purposed to hydrogen. Not discussed is how this will be done. Most proposals and trials look at mixing hydrogen into methane, but hydrogen needs 50% more volume per joule of output, increasing required gas flows; it also burns much hotter. These change the flame characteristics, requiring conversion of hydrogen combustion devices. (Conversion is also required to avoid hydrogen leakage and embrittlement, owing to the small molecule size in comparison with that of methane.) Because of the conversions for thermal and volume-flow reasons, diluting the grid in stages such as 20%, 40%, 60%, 80% and 100% hydrogen would require multiple conversion exercises[56], each on the scale of the conversion from town gas to North Sea gas; converting straight from methane to pure hydrogen is one single (albeit slightly dearer) conversion exercise and therefore much cheaper, less disruptive and manageable in terms of human resource availability. This suggests that roll-out should not be by such stages, but should instead be 100% conversions of different areas, sequentially expanding from hydrogen hubs

[55] Patent family WO2019GB52168

[56] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/760508/hydrogen-logistics.pdf

– probably using the British government's Low Carbon Clusters[57] as those initial hubs. This is at least partially accepted p105.

FES 2021 expects (p94) that nearly all heating will be converted to three main technologies: heat pumps and electric heating, burning hydrogen in boilers, and hybrids of the two. The hydrogen would be carried in National Grid gas pipelines, converted from carriage of methane. Please see above (Residential demand) for the shortfalls of this.

57 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/803086/industrial-clusters-mission-infographic-2019.pdf

Some Electricity Generation Technologies

Bioenergy

With an increasingly insecure food supply, and shortages world-wide, pressure on agricultural land must be minimised. Today, the challenge is the loss of Ukrainian supply, but that's only a foretaste of what global warming has in store for the planet even without any wars to exacerbate matters. As sea levels rise, fertile deltas and plains will be flooded, and as semi-desert desiccates, so farmland is lost and adjacent farmland rendered less productive. This will not be compensated for in full, or anything close to fully, by bringing new regions of marginal land (especially in the taiga and boreal forests) into production: not only are these distant from both the inputs and transportation links needed, but also converting those lands will again add to global warming. Therefore, the availability of fuel for bioenergy will always remain quite restricted.

As the report points out, "negative emissions from Bioenergy with Carbon Capture and Storage (BECCS) and other Greenhouse Gas Removal (GGR) methods are still required to offset emissions from sectors of the economy which are 'hard to abate'." However, that means that if emissions can (in practical terms) be abated in other ways, it should be. That means avoiding fossil fuelled generation + CCS, and hydrogen from methane + CCS, since sufficient large-scale long-duration storage (especially if naturally inertial) can replace the former, and electrolysis can replace the latter. The costs of emissions from such technologies should reflect the costs and inefficiencies of the BECCS required to compensate for them.

It is notable that about ¾ of energy input to BECCS (biomass with CCS) is shown as losses, and only ~¼ as electricity output. BECCS is an exceedingly inefficient technology as well as an extremely expensive one, for which reasons the need for it should be avoided where possible, e.g. by deriving hydrogen from electrolysis rather than methane reformation and (necessarily imperfect) CCS, and by large-scale long-duration electricity storage rather than fossil fuelled power stations with (necessarily imperfect) CCS.

Moreover, the forecasts for BECCS are for balancing the output of combustion of fossil fuels, and ignore the need to balance emissions in their extraction, refining and transportation; considering those aspects would require a huge and unsustainable increase in forecast BECCS.

Gas

Although "transitioning towards Net Zero while maintaining a reliable and affordable energy system for all will require a continued, if different, role for natural gas as it cannot be used in a Net Zero world without its emissions being captured", there is little realisation of the costs and inefficiencies of CCS and CCUS[58]. Equally, there is insufficient appreciation of the low costs and vast benefits of the large-scale, long-

58 https://www.storelectric.com/carbon-capture-use-and-storage-ccus-and-ccs/

duration, naturally inertial storage that is available today and could, if rolled out, make gas generation (even with CCS) unnecessary as well as comparatively expensive and inefficient, whether for energy security, balancing, reserve, grid stability, power quality or the other purposes for which power stations are used today. And it doesn't have to cost the grid anything: just to put the right contract structures in place, following which it would be built and operate commercially.

As gas consumption reduces, so power stations need to charge increasingly unaffordable amounts for just being there in reserve, and for frequently warming up "just in case". And warming up causes emissions too, which then entail more BECCS. If they are not paid such exorbitant amounts per unit of energy produced, then there will be no business case to keep them open.

There is absolutely no need for shale gas, whose extraction and refining are enormously polluting and emitting, and which would require vast expansion of BECCS to compensate.

Nuclear

Nuclear energy is under-valued by the current contracting systems. This is because we pay the same for all electricity regardless of its value – see Paying for What We Need, above. This leads to the perception that a high "strike price" is uneconomic for the electricity system as this price is compared with the CfD price of intermittent, asynchronous wind or solar energy.

A second value of nuclear is its energy density per unit area: ~5GW per square mile, as compared with wind (~60MW) and solar (~30MW).

A third value is that it can be put in parts of the country that are further from wind, saving on grid network costs – and these savings are additional to the network savings from its dispatchable / baseload nature.

And while it is highly cost-effective for long-duration storage to provide balancing for variable demand, it is much more cost-effective for nuclear to provide baseload input to match baseload demand.

Renewables Mix

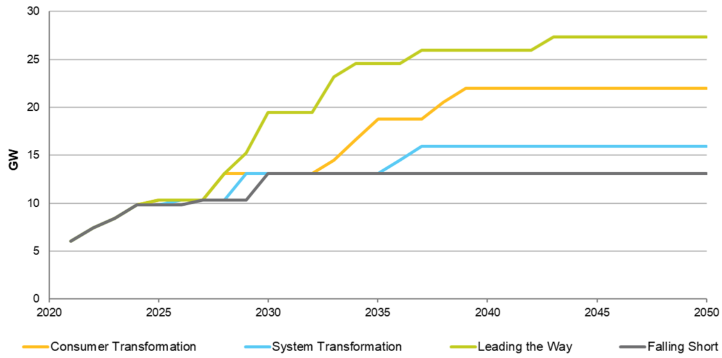
As analysed by Nottingham University for the Energy Research Accelerator[59], the monthly generation profiles of solar and wind are mirror images of each other. Therefore the right proportions of each (roughly 20-25% solar) will provide monthly output averages that map seasonal variation in demand.

There will be shorter-term fluctuations in demand, and multi-year cycles in renewable generation. These can be largely accommodated by a ~10-25% over-build of renewable generation, which is much cheaper than any storage strategy.

[59] https://www.era.ac.uk/Medium-Duration-Energy-Storage

There may be a residual quantitative case for hydrogen generation, but the load factors are likely to be so low that no economic case will ever be affordable.

Interconnectors



FES relies on interconnectors for actual demand, which one cannot do: by 2040 every Western European country except Iceland, Norway and Switzerland will rely on imports during times of system stress. Iceland is too remote (exceedingly costly interconnectors, very much longer than any other in the world) and low spare capacity (evaluated at 1GW). Norway will prioritise exports to Scandinavia and Germany, and Switzerland to its neighbours. Brexit gives our neighbours a political imperative to cut us off during times of system stress, such as after sunset on a windless winter evening and weather patterns that extend this for days, which frequently cover neighbouring countries. Therefore we cannot rely on interconnectors to keep our lights on when we need them to; their proper place is to ensure that normal energy prices are reasonable. This is a brief summary of a previous analysis[60].

The consequence of this is plans for a totally inappropriate surge in interconnection from 5GW to 19-28GW by 2037. This will merely add costs to the system by cannibalising revenues from storage, which we will still need for when interconnectors cannot provide the energy. And the capital cost per GW of interconnection to (say) the Netherlands is very similar to the cost of same-sized 8-hour adiabatic CAES, on which the country can rely.

Also ignored is the fact that interconnectors are DC, i.e. asynchronous. Therefore any such interconnection requires further capital investment and both operational and contractual costs to provide stability services, for example using synchronous condensers – £328m for six years from five plants in January 2020, with needs increasing in parallel with renewable generation and interconnection. These stability services can be provided much more cheaply by almost any long-duration storage technology, provided that they have a suitable revenue stack.

[60] https://www.storelectric.com/interconnectors-and-imports/

Energy Storage and Flexibility

FES 2022 compliant scenarios require 32-52GW of electricity storage. Comparing the total GW and GWh of storage yields an average storage duration of 3.6 hours for the three Net Zero compliant scenarios. Given that nearly all battery storage is typically 1 or 2 hours, also stated in the report, that means that at least as much longer-duration storage is needed, of 4-12 hours duration.

As a result of all the dreadful errors described above in this analysis, storage capacity (excluding the grossly over-estimated V2G) is forecast at 23-52GW (23GW is the non-compliant scenario). While this looks substantial, this is only nameplate capacity and doesn't even consider the essential measure of duration. Indeed, most of the discussion is about batteries, which cannot cost-effectively scale up in this way. Nor do the batteries provide the other services that inertial storage does: up to 6 batteries are needed to provide the entire range of services that a single inertial storage facility can deliver concurrently from a single same-sized unit. Not to mention that there are not enough resources in the earth's crust to build them. Batteries are indeed an unaffordable and inadequate option[61].

The report does mention longer-duration storage, notably pumped hydro, but offers no way in which it will be incentivised: there are no such projects on the table that were not on the table a decade ago, and they have not proceeded due to systemic regulatory and contractual problems addressed elsewhere in this analysis. And CAES, the most cost-effective of the lot, is not even mentioned – solely because the ministry, regulator and grid have not enabled a first-of-a-kind to be built.

The discussion on flexibility perpetuates the insistent misunderstanding of a 2012 Imperial College report[62] which said not to talk about storage, but about flexibility ***and duration***, stating that "Resource adequacy requires several hours of storage duration, if peaking generation is to be displaced securely, based on the shape of the demand profile derived for 2030." What is the point of flexibility if it is exhausted part-way through need, such as after sunset on a windless winter evening, when it's needed through the entire evening peak and even overnight? Flexibility must never be discussed without duration, however much reports such as this insist on doing so.

And this ignores the fact that their identified need for storage is so under-stated, which is why whole-system costs are escalating exponentially.

Flexibility

FES brings out their persistent, insistent error that "Flexibility is crucial to operating the energy system…" A focus on "flexibility" without the concept of "duration" has been a mantra in government, grid and regulatory circles ever since they started

[61] https://www.storelectric.com/batteries-expensive-and-inadequate-solutions/
[62] https://www.imperial.ac.uk/media/imperial-college/energy-futures-lab/research/Strategic-Assessment-of-the-Role-and-Value-of-Energy-Storage-in-the-UK.pdf

misunderstanding a 2012 Imperial College / Carbon Trust report[63] that focused on flexibility but also analysed duration, identifying that the greatest value of storage was at 6 hours' duration – they ignored that last part (e.g. p12 footnote "*Resource adequacy requires several hours of storage duration, if peaking generation is to be displaced securely, based on the shape of the demand profile derived for 2030.*").

Flexibility is defined exclusively as "driven as much by peaks and troughs of electricity supply as by peak demand" (elsewhere, these are "times of system stress", periods of high renewables / low demand, or high demand / low renewables), i.e. in GW. There is much less importance placed on duration / volume of that need, i.e. GWh. Indeed, "Large amounts of flexibility with duration of a few hours will be needed to match supply and demand within day. This includes up to 35 GW of electricity storage with an average discharge duration of less than 4 hours by 2050". This means that GW rather than GWh will be rewarded and procured. Thus, on a windless winter evening, flexibility is likely to be exhausted by 6pm or, at best (4 hours after sunset) 8pm. Other sources of flexibility (DSR) are inherently much shorter duration. This myopia guarantees black-outs, frequent and widespread, as the energy transition progresses.

Inter-seasonal storage of 11-56TWh is wanted. This is not correlated with a GW size.

Flexibility without duration will not keep the lights on after sunset on a windless winter day: DSR, V2G and batteries would be exhausted by 6pm whereas the need continues through the evening peak and overnight. Weather patterns reducing renewable generation to below 10% of nameplate capacity (and often close to zero) can extend this for days, even as far as the fortnight of the "*kalte Dunkelflaute*" ("cold dark doldrums") that covers almost the entire continent and therefore figures large in French and German energy transition plans; with more restricted duration (to a few days) and geography (to a few countries), these weather patterns are frequent.

In relation to the energy system flexibility is discussed only with respect to evening peak demand in winter, and daytime minimum demand in summer. Yet troughs in renewable generation are as important as peaks in demand, and will become ever more so as renewable penetration increases.

Security of supply is assumed to continue to be provided by gas. But utilisation rates for power stations are so low that their prices are climbing fast, and even so they are closing as they age and new ones are not being built. This source of security not only violates 2050 targets but will also fail as gas power stations age and close. As with gas storage, there is no reimbursement for reserve capacity; and such capacity should be reimbursed preferentially if zero-carbon.

In the entire treatment of demand-side flexibility (residential, commercial, industrial, vehicle, electrolysis), duration is not mentioned once.

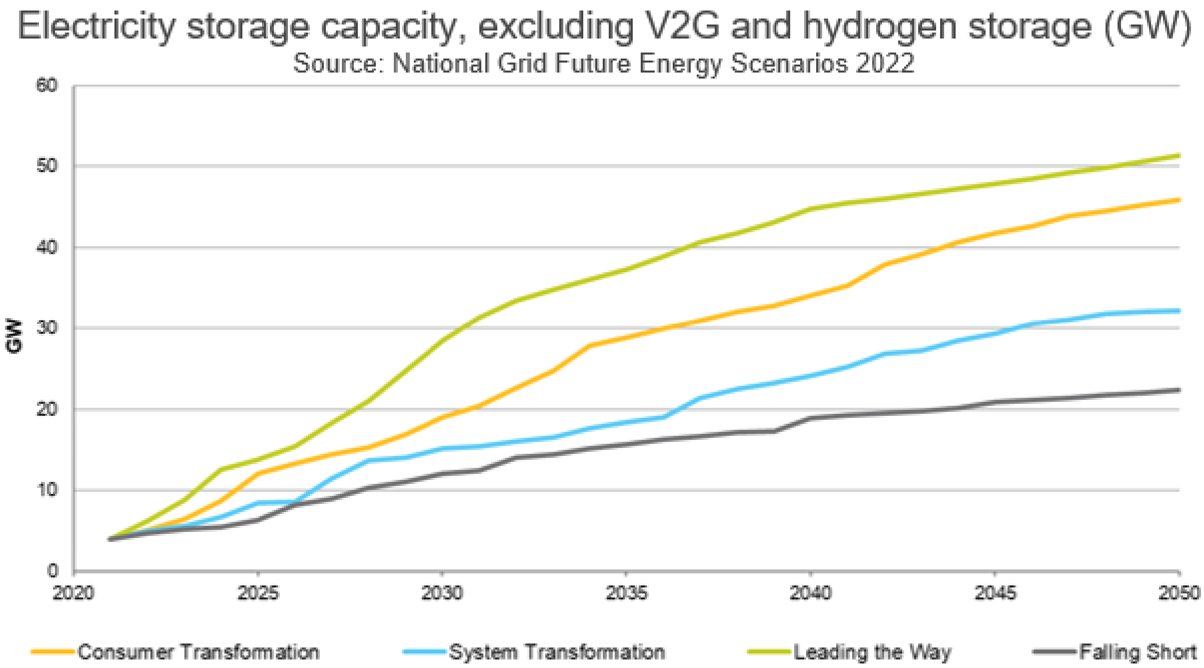
[63] https://www.imperial.ac.uk/media/imperial-college/energy-futures-lab/research/Strategic-Assessment-of-the-Role-and-Value-of-Energy-Storage-in-the-UK.pdf

How Much Storage Is Needed?

By coincidence, the UK electricity system's required supply margin is roughly equal to the expected zero-carbon dispatchable and baseload generation (e.g. nuclear, biomass, BECCS but ignoring gas + CCS). By a simple but rigorous calculation of the need for storage[64], the gigawatts of storage required is therefore roughly equal to peak demand, which ranges from 97.5GW to 114.2GW (the low figure is the Leading the Way scenario; the high figure is Falling Short, which is close to Consumer Transformation).

As the zero-carbon generation is likely to be prioritised, and the storage kept in reserve, the duration of storage required is equal to all demand over the longest period (2 weeks) of low-renewable generation, which coincides with extreme demand that will be increasingly extreme for electricity as heating is decarbonised, minus the output during that period of zero-carbon generation, plus a reserve, which we estimate at 46-69TWh, based on National Grid's forecast demand in their three Net Zero compliant scenarios.

This is a very different amount of storage from National Grid's calculation:



64 https://www.storelectric.com/calculating-the-need-for-storage/

Regulatory Issues

Paying for What We Need

In the current electricity system, the price per MWh of electricity is the same regardless of its value. Thus 1MWh of intermittent, asynchronous generation is paid the same as 1MWh of dispatchable/baseload, synchronous generation. The former is much less valuable as it requires the procurement and connection of balancing, ancillary, stability, power quality and resilience services; the latter provide such services as a by-product of the energy. Therefore its energy is much more valuable.

The grid has made big strides towards remedying that anomaly by creating revenue streams to reward those additional benefits. However the way in which this has been done leads to a great deal of salami-slicing of outputs[65], which make new plants with broad capabilities and large size impossible to finance and build unless covered by a special long-duration financial instrument to guarantee its future profitability.

Moreover, even these partial contractual improvements ignore the benefits to the grid network itself from dispatchability (which requires much less capacity per unit of energy carried than does intermittency) and synchronicity (which means that additional services don't need to be sourced and connected up, and there are no "disturbed areas" between the intermittent generation and its balancing and stability services.

Carbon Price

We expect that emissions prices, in whatever form (e.g. carbon tax, emissions permits and trading) will increase rapidly towards the ranges (as evaluated by the British government in 2021[66]) that range from central figures of £241/tCO2e (pounds per tonne of CO_2 equivalent) in 2021, rising to £378/tCO2e by 2050 (and a "high series" range of up to £568/tCO2e in 2050).

Different sources of fuels should have emissions prices attached based on their sources; for example, gas and oil from shale have much higher emissions than those from onshore wells, with offshore being intermediate.

Recommendations

Apart from a recognition of the above problems, and policies to suit, a new approach to regulation and contracting electricity[67] is needed which will, within the price paid (and therefore without need for special financial instruments = market distortions and subsidies), incentivise:

- ♦ Minimise total system costs, both capital and ongoing;
- ♦ Investment for the long term, including in large-scale flexible technologies;
- ♦ Enable large-scale flexible technologies to compete;

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65 https://www.storelectric.com/wp-content/uploads/2021/08/Revenue-Stacking-and-Salami-Slicing.pdf
66 https://www.gov.uk/government/publications/valuing-greenhouse-gas-emissions-in-policy-appraisal/valuation-of-greenhouse-gas-emissions-for-policy-appraisal-and-evaluation
67 https://www.storelectric.com/a-21st-century-electricity-system/

- Incentivise cleanness of all technologies without a penny spent on doing so;
- Incentivise the introduction of new technologies, again without a penny spent;
- Make the grid once more one of the world’s most reliable, resilient and affordable.

This needs to be matched by other regulatory overhauls such as:

- A correct regulatory definition of storage[68];
- Enabling long-term contracts[69];
- Contracts to cover multiple revenue streams[70], not just from the System Operator but also the Transmission Operator where a project will benefit both[71];
- Enabling projects’ benefits to be evaluated and rewarded on their own merits rather than destroying developers’ incentives by artificially competing each developer’s best ideas[14];
- Revising the OFTO regime to enable offshore energy generators to benefit from onshore investment in relation to both new and existing installations[14].

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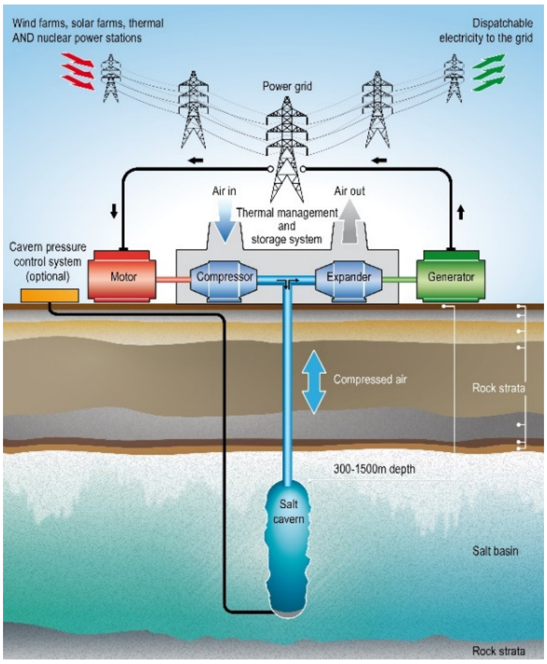
68 https://www.storelectric.com/wp-content/uploads/2021/03/Regulatory-Definition-of-Storage.pdf
69 https://www.storelectric.com/wp-content/uploads/2021/03/Issues-with-Ever-Shortening-Contract-Durations.pdf
70 https://www.storelectric.com/wp-content/uploads/2021/08/Revenue-Stacking-and-Salami-Slicing.pdf
71 https://www.storelectric.com/wp-content/uploads/2021/03/Enabling-Renewables-to-Power-Grids.pdf

Mark's Blog

Personal blog of Mark Howitt, founding director and CTO of Storelectric Ltd and recognised international expert in the energy transition

About Storelectric

Storelectric (www.storelectric.com) is developing transmission and distribution grid-scale energy storage to enable renewables to power grids reliably and cost-effectively: the world's most cost-effective and widely implementable large-scale energy storage technology, turning locally generated renewable energy into dispatchable electricity, ***enabling renewables to power grids cheaply, efficiently, reliably and resiliently***.



- ♦ Innovative adiabatic Compressed Air Energy Storage (Green CAES) will have zero / low emissions, operate at 68-70% round trip efficiency, levelised cost significantly below that of gas-fired peaking plants, and use existing, off-the-shelf equipment.
- ♦ Hydrogen CAES technology converts & gives new economic life to gas-fired power stations, reducing emissions and adding storage revenues; hydrogen compatible.
- ♦ Storelectric has also patented the use of the heat of compression to catalyse electrolysis, for efficiency and scalability.

Both CAES technologies will operate at scales of 20MW to multi-GW and durations from 4 hours to multi-day, more cost-effective and configurable than any other technology to suit a vast range of applications / use cases, concurrently delivering grid stability based on real inertia. With the potential to store the entire continent's energy requirements for over a week, global potential is greater still. In the future, Storelectric will further develop both these and hybrid technologies, and other geologies for CAES, all of which will greatly improve storage cost, duration, efficiency and global potential.

About the Author

Mark Howitt is Chief Technical Officer, a founding director of Storelectric. He is also a United Nations (UNECE) expert advisor in energy transition technologies, economics, regulation and politics – invitation here. He is also a member of the UK advisory team to the IEA (International Energy Agency), member of the Energy Storage Steering Group of the Renewable Energy Association, and a regular consultee to the British energy ministry, regulator and National Grid.

A graduate in Physics with Electronics, he has 12 years' management and innovation consultancy experience world-wide. In a rail multinational, Mark transformed processes and developed 3 profitable and successful businesses: in commercialising a non-destructive technology he had innovated, in logistics (innovating services) and in equipment overhaul. In electronics manufacturing, he developed and introduced to the markets 5 product ranges and helped 2 businesses expand into new markets.

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