PERSPECTIVES ON TRANSFORMING UTILITY BUSINESS MODELS

Paper 6 – Multi-Vector Business Models

July 2024

INTRODUCTION

There are already business models that span energy vectors; for example, many energy retailers will supply both electricity and gas, including through dual-fuel tariffs. Additionally, in terms of network infrastructure, there are some multiutilities that have spanned energy vectors (electricity, gas, and/or heat networks) or cross sectors (for example electricity and water). These multiutility businesses have been able to deliver some economies of scale through combined multiskilled work forces, as well as through shared reporting centers, groundworks and civil works contractors, and call-handling facilities. However, examples are relatively few, and some have reverted to single-vector or single-sector business models. While there are examples of combined electricity and gas utilities in the United States, regulatory and market barriers have limited their ability to integrate their businesses and leverage opportunities that might have been expected from having common footprints serving the same groups of customers.

Nevertheless, it is now becoming widely recognized, particularly during a period of transition from fossil fuels to carbon-free alternatives, that energy must be considered from a whole system perspective. The future paradigm is that while delivery of energy will continue to be through electricity and natural gas, it will also be through hydrogen and various liquified fuels. In addition, there will be greater interaction between these energy vectors, for example in terms of energy conversion, arbitrage, and storage, as well as through hybrid/dual-fuel applications. There are also reversible interactions such as electricity to hydrogen (electrolysis) and hydrogen to electricity (direct combustion in gas turbines or fuel cells). The future energy system will also have greater interdependencies with other sectors, for example transport, telecommunications, water, and carbon capture and storage. Each of these sectors will become increasingly dependent on the others. Only through understanding and exploiting opportunities around these interactions and interdependencies will it be possible to achieve an optimized overall energy system and hence the most effective and sustainable business models.

As energy vectors become more integrated, energy strategies will emerge that are able to capitalize on the benefits of a coordinated multi-vector and inter-sector approach in preference to single-vector/single-sector strategies that are unable to fully exploit the synergies of coordinated multi-vector energy systems. A feature of multi-vector energy systems will be the emergence of subnational as well as national energy strategies optimized to meet region-specific energy supply and demand characteristics as well as deliver national energy decarbonization and security-of-supply objectives.

It follows that utility business models relating to energy supply and demand will become more complex with regional specificity in terms of the energy vector mix, but better aligned overall to the national goals of energy decarbonization, affordability, and security of supply. An option for governments and regulators would be to permit utilities to have multi-vector regulatory asset bases (RABs) and deliver multi-vector services. In the absence of such an integrated regulatory framework, an alternative would be for utilities serving different energy vectors or sectors to form strategic partnerships or joint ventures. Whichever model is adopted, it is helpful to understand the challenges and opportunities by first exploring the implications of a multi-vector energy system and the benefits to both utilities and customers of applying a whole energy system framework.

CROSS-VECTOR INTERACTIONS

Defining characteristics of the future multi-vector energy system will be the interactions and interdependencies between energy vectors, including between electricity, gas (natural, blended, and hydrogen), petroleum products (for transport), and heat (heat networks).[1] Hitherto, these vectors have been regarded largely as independent, other than in the context of certain energy conversion processes such as electricity generation from gas [for example combined-cycle gas turbines (CCGT), open-cycle gas turbines (OCGT), and gas engines] and the production of hydrogen by steam methane reformation.

Energy Demand

The materiality of these interactions and interdependencies will depend on the ultimate energy vector mix adopted to meet energy demand across sectors, for example:

- Petroleum products, electricity, and hydrogen (or hydrogen fuel cells) for both rail traction and road vehicles
- Petroleum (diesel), hydrogen (or ammonia), and electricity for marine transport
- Jet fuel, AVGAS, bio-based sustainable aviation fuel (SAF), and hydrogen (direct combustion or fuel cells) for aviation
- Coal (coke), natural gas, electricity, and hydrogen for high-energy industrial processes such as production of steel, cement, glass, or ceramics, for example
- Electricity, natural gas, and hydrogen for commercial and public built-environment space and water heating
- Electricity, natural gas, and hydrogen (or blended gas[2]) for domestic space and water heating, including hybrid applications such as combined heat pump/gas boiler systems

Energy Supply

Similarly, the materiality of these interactions and interdependencies will depend on the ultimate energy vector mix adopted for energy supply, for example:

- Natural gas, nuclear, biomass, wind, solar, wave, tidal, geothermal, and hydrogen for electricity production
- Cogeneration and waste burning for electricity and heat production to supply electricity and heat networks
- Energy arbitrage applications, for example, using offshore wind farms for hydrogen production through electrolysis during periods when electricity supply capacity exceeds demand
- Colocating battery energy storage systems (BESS) with onshore wind or solar photovoltaic (PV) farms as an arbitrage option to mitigate the impact of network constraints and improve annual generation load factor
- Natural-gas-fueled electricity generation abated through carbon capture and storage (CCS)
- Natural gas for blue hydrogen production, both for electricity generation and as a source of transport fuel
- Agriculture and forestry for production of biomass, and electricity generation through bioenergy with carbon capture and storage (BECCS)
- Anaerobic digestion at sewage treatment plants for electricity production from methane abated through CCS

The diagram in Figure 1 illustrates some of the potential future multi-vector options for energy supply and demand serving different sectors during a period of low-carbon energy transition. The suggested relative contribution from each energy vector is representative rather than definitive and in practice will vary between nations, states, and regions.

1 Although heat is not strictly an energy vector, the growth of heat networks requires that heat be considered a separate vector from an infrastructure perspective.

2 Ignoring minority fuels for residential space and water heating such as liquified petroleum gas (LPG), oil, wood, coal products, and biofuels.

FUEL SOURCE / PURPOSE	Electricity Production	Hydrogen Production	Energy Storage	Built Environment	Industrial Processes	Transport
Electricity		MAJOR	MAJOR	MAJOR	MAJOR	MAJOR
Natural Gas Unabated	REDUCING			REDUCING	REDUCING	
Natural Gas with CCS	INCREASING	INCREASING			INCREASING	
Hydrogen	INCREASING		INCREASING	MINOR	MINOR	INCREASING
Petroleum Products					MINOR	REDUCING
Biofuels	MINOR				MINOR	MINOR

Source: Millhouse Power

Figure 1. *Potential future multi-vector options for energy supply and demand*

A WHOLE ENERGY SYSTEM APPROACH

As stated above, a whole energy system approach means understanding not only the interactions and interdependencies between individual vectors of the energy system, but also, from a wider economy perspective, the key interactions across the boundary between the energy system and interdependent sectors[3] as shown in Figure 2.

WIDER ECONOMY

- Telecoms
- Water & Sewerage
- Sport & Leisure
- Industry & Commerce
- Natural Capital
- Public & Residential
- Transport
- Agriculture & Land Use

ENERGY PRODUCTION

- Onshore Renewables
- Wave & Tidal
- Offshore Wind
- Bio-Energy
- Hydrogen Production
- Thermal Plant
- Hydrogen Storage
- Oil & Gas Production

ENERGY INFRASTRUCTURE

- Onshore Electricity Networks
- Heat Networks
- Offshore Transmission & Interconnectors
- EV Charging Infrastructure
- Hydrogen Networks
- CCS
- Natural Gas Networks

Source: Millhouse Power

Figure 2. *A whole energy system approach illustrated across a wider economy perspective*

This in turn means applying systems thinking to the overall design of the energy system, from energy production through transportation to end use, extending across all energy vectors and interdependent sectors. Drivers and enablers of low-carbon energy transition—such as policy, legislation, markets, regulation, codes, and standards—must also be considered as part of the equation. A whole energy system approach, as shown in Figure 3, needs also to embrace individual, local, regional, national, and even international perspectives (that is, with regard to fuel imports and exports as well as international electricity markets governing power flows over electricity interconnectors). The overall objective of systems thinking is to achieve coherence by design, embracing energy transition through understanding the impacts of interactions within and beyond the physical energy system.

3 An interdependent sector is one that is dependent on energy and that energy is dependent upon.

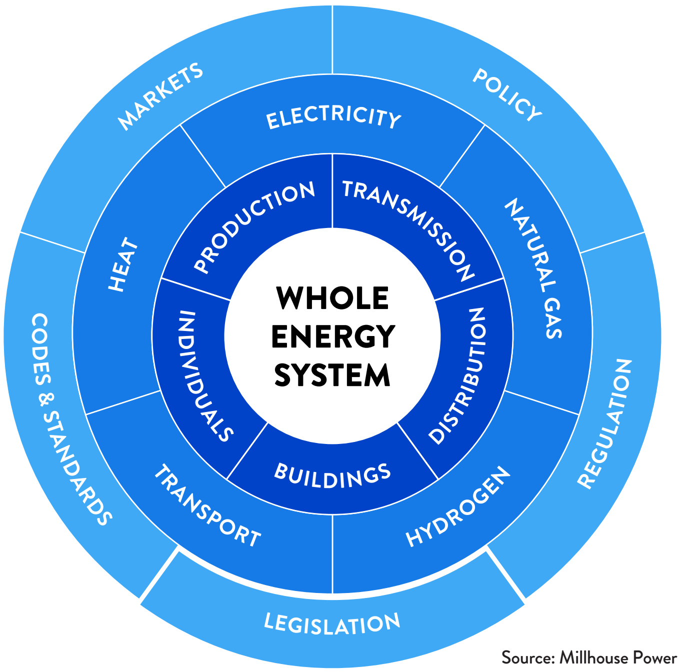

Figure 3. A whole energy system approach considers the overall design of and interactions within the energy system

A Whole Energy System Framework

In order to apply systems thinking to any given application of energy production, delivery, and usage, it is helpful to apply a whole energy system framework as a basis for identifying and mapping interactions and interdependencies between energy vectors and interdependent sectors,[4] along with the associated drivers and enablers of those interactions. A simplified version of such a framework is illustrated in Figure 4. However, in practice, interactions would be considered at a lower level of abstraction, for example different types of renewable generation, industrial processes, and transport.

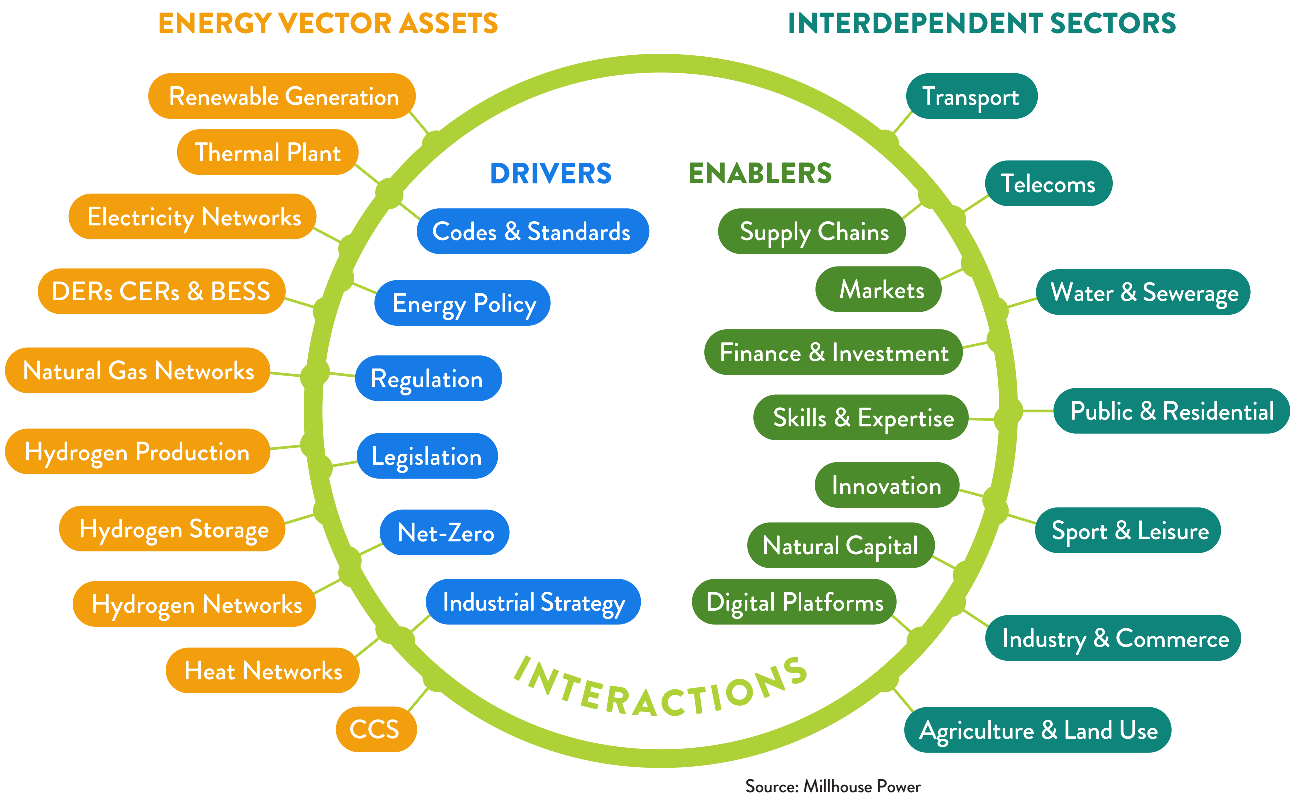

Figure 4. *A simplified version of a whole energy system framework showing drivers and enablers of interactions between energy vectors and interdependent sectors*

4 Adjacent sectors are the subject of a dedicated paper in this series.

A whole energy system approach will entail many interactions and interdependencies between energy vectors, and between the energy sector and interdependent sectors. The materiality of these interactions and interdependencies will depend on the ultimate energy vector mix adopted for energy supply and energy demand, but the objective in all cases is to maximize cross-vector synergies and avoid conflicts through an integrated approach to energy system planning. The application of the above whole energy system framework is illustrated by the following use case.

MULTI-VECTOR USE CASE – ELECTRICITY, NATURAL GAS, AND HYDROGEN

Having outlined the elements of a whole energy system framework, a deeper dive into a specific use case will help illustrate the characteristic interactions and interdependencies of an energy system based on a coordinated cross-vector approach to energy supply and demand. The following use case is based on the following assumptions:

- **Electricity and either hydrogen or blended gas** are used to supply residential hybrid heating systems (that is, a gas boiler and heat pump) or to supply the energy for heat networks.
- **Electricity and hydrogen** are used to supply energy-intensive industrial processes such as steel, cement, glass, or ceramics.
- **Hydrogen** is produced by both steam methane reformation with CCS (blue hydrogen) and electrolysis (green hydrogen).
- **Green hydrogen** is produced from offshore wind turbines at times when output either exceeds national demand or would otherwise be curtailed due to transmission constraints or for operability reasons, for example due to the need to constrain on a minimum level of synchronous generation to maintain adequate system strength (fault level and inertia).
- **Hydrogen** is stored (for example in salt caverns) as a means of long-duration energy storage to supply hydrogen-fueled CCGTs during sustained periods of low wind volumes.
- **Hydrogen fuel cells and/or hydrogen combustion** are used for heavy goods vehicles and long-haul buses.

Business Model Implications

From a whole energy system planning perspective, the business model imperative surrounding this use case would be to ensure coordination between development of electricity (generation, transmission, and distribution) and hydrogen production (both blue and green hydrogen), storage and transportation, and CCS infrastructure, also taking account of the energy vector options between electricity and hydrogen for supplying industrial and transport sectors.

Implicit sources of cross-vector and inter-sector interaction specific to this use case can be illustrated using the framework in Figure 4 depicting the vectors and sectors specific to this use case.

It will be apparent that each of the drivers and enablers represented in the framework diagram in Figure 4 will have a role in ensuring the effectiveness of these interactions, and hence the viability of associated business models. The optimum business model would be one where decisions regarding capital investments, operational planning, and real-time operations are supported by regulatory obligations and incentives, industry codes, and market signals. This would require removal of any current barriers to cross-vector optimization from investment planning through to operational timescales, for example due to concerns over cross-subsidies between organizations operating across different energy vectors or even within the same energy vector.

Applying the above framework identifies the following cross-vector and cross-sector interactions, along with the relevant drivers and enablers.

ENERGY VECTOR INTERACTIONS
• **Wind generation** and **hydrogen production** through electrolysis (ideally colocated to avoid transmission constraints) • Blue **hydrogen production** from **natural gas** through steam methane reformation with CCS • **Hydrogen production** and **storage** (ideally colocated to minimize hydrogen pipeline infrastructure) • **Hydrogen production, storage, and transportation** to supply hydrogen-fueled **thermal generation** • **Hydrogen, natural gas, and electricity** as a potential hybrid option for domestic space and water heating through heat pumps and gas boilers using blended gas
CROSS-SECTOR INTERACTIONS
• Blue **hydrogen production** and **CCS** infrastructure • **Natural capital** opportunities for offshore wind (e.g. high wind speed and shallow seabed locations), hydrogen storage (such as salt caverns), and carbon sequestration (such as porous rock strata) • **Natural gas, hydrogen, and CCS** infrastructure as a part of an overall strategy for decarbonizing hard-to-abate industrial processes • Energy and **transport** sectors in terms of their respective needs for **hydrogen production, storage,** and **transportation** infrastructure as part of an overall national hydrogen strategy
DRIVERS
• **Net-zero** commitments and legally binding targets with regard to greenhouse gas emissions • **Energy policy** to decarbonize the electricity system subject to security of supply • **Regulatory** frameworks for hydrogen infrastructure and CCS • **Green industrial strategy,** including commitments to decarbonize hard-to-abate energy-intensive processes • National and local government **planning policy** reforms necessary to facilitate development and accommodation of energy infrastructure
ENABLERS
• **Energy storage** capacity and **markets** (for example a market that values the real value of long-duration energy storage) • New **industry codes and standards** surrounding hydrogen and its interaction with electricity • Government, industry, and **supply chains** through commitment to energy policies that encourage investment in both infrastructure and extraction or import of critical raw materials • **Skills development** and retraining programs • **Innovation** funding

Geospatial Considerations

Having described the role of a whole energy system framework for managing both cross-vector and inter-sector interactions and interdependencies, facilitated through drivers and enablers, a further important consideration in planning and delivering a whole energy system is that from a geospatial perspective, recognizing region-specific challenges and opportunities. This emphasizes the need for a whole energy system approach to reconcile national objectives with both regional and local strategic energy plans. The following examples outline some typical geospatial considerations relevant to the creation of multi-vector business models.

GEOSPATIAL FACTORS
• Natural capital, such as naturally occurring energy resources (wave, tidal, and geothermal, for example) • Geographic constraints relating to choices of electricity generation technology, such as availability of suitable locations for offshore wind, availability of suitable coastal or major riverside locations for conventional nuclear power stations (to provide a source of cooling water to handle the heat produced by nuclear fission), and landscapes suitable for development of pumped hydro schemes • Naturally occurring or derived energy storage or carbon sequestration opportunities, such as salt caverns and depleted gas fields • Localized industrial activity or major transport hubs, which might enhance the business case for establishing hydrogen and carbon capture, utilization, and storage (CCUS) clusters • Local heat networks supplied by cogeneration in conjunction with water source heat pumps • Hydrogen-fueled trigeneration supplying electricity, heat, and cooling to commercial clusters • Residential hybrid heating systems based on heat pumps, batteries (both conventional and heat), and natural or blended gas • Multi-energy systems (MES) consisting of electricity, heat, cooling, fuels, and transport, optimally interacting within a district, city, or region • Hybrid transportation systems based on electricity, hydrogen fuel, and hydrogen fuel cells

MULTI-VECTOR OPTIONS FOR UTILITIES

The delivery of a decarbonized whole energy system will involve many interdependencies and potential trade-offs between energy vectors from both energy supply and demand perspectives. This gives rise to numerous new low-carbon multi-vector business model opportunities for utilities.

By definition, a multi-vector business model means expanding the reach of a utility beyond the boundary of a single energy vector such as electricity, and, in the case of network operators, potentially beyond the bounds of their current regulatory remit. Following are some examples of multi-vector options for utilities.

Energy vector conversion: In its most simple form, the model could be one whereby a utility provides energy from one vector to supply a conversion process; for example, a utility delivering electricity to an electrolyser to produce green hydrogen, or natural gas to produce blue hydrogen, for onward distribution to customers as a source of residential and commercial space and water heating, or delivering electricity to a large-scale ground or water-source heat pump to supply a district heating network.

Multi-vector utility model: Despite inherent constraints enforced by regulatory requirement for business and retail market separation, there are examples of combined electricity and gas utilities, one of the best being Avangrid Networks[5] in the United States, which owns and operates eight electricity and natural gas utilities, some of which are multi-utility in their own right, operating both electricity and gas networks. Together the Avangrid companies, shown in Figure 5, serve more than 3.3 million customers in New York and New England.

5 https://www.avangrid.com/aboutus/

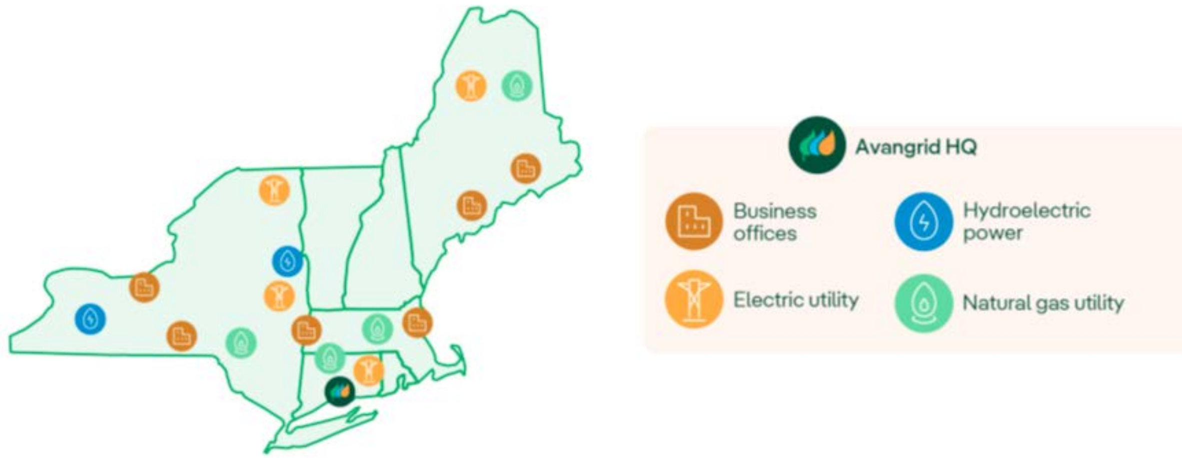

Figure 5. The Avangrid network of utilities Source: Avangrid Networks

Multi-vector regulated asset base model: A more ambitious option would be for governments and regulators to permit utilities to have multi-vector regulatory asset bases (RABs) and deliver multi-vector services. While this might seem intuitively sensible, it is an option that has traditionally been resisted due to concerns over cross-subsidies between customers served by different energy vectors and/or non-energy networks. Cross-subsidy is less of a concern in respect to energy suppliers who are able to offer dual-fuel (gas and electricity) contracts, albeit with quantities supplied by each energy vector metered and charged separately. A further potential opportunity is for new customer service models to replace the traditional energy commodity model (for example, providing warmth, air cooling, or EV charging as a service).[6] Notwithstanding current reservations by energy regulators over cross-subsidies, there might be benefits in exploring the potential economies of scale, and ultimately, cost savings to customers, of a multi-vector regulated asset base model.

Utility mergers and joint ventures: A further option (subject to regulatory, federal, or state approval[7]) is for utilities to consider mergers, for example between electricity and gas or heat network operators covering similar geographic footprints. This model has previously been applied to multi-sector utility models such as electricity and water but with each sector separately regulated and ring-fenced to avoid cross-subsidies. A variation on the merger model is for utilities serving different energy vectors to embark on a joint venture to create an outsourced network management company providing network services to the parent companies. The outsourced company could be resourced from the parent utilities through Transfer of Undertakings (Protection of Employment) regulations (TUPE) transfer arrangements, with the parent companies adopting a thin ownership model, retaining a small number of staff to oversee the contractual performance of the outsourced organization. In addition to provision of new connections, routine preventive maintenance, and fault repairs, the outsourced organization would typically be responsible for procurement of network assets, materials, and contracted services, and for network planning, design, and an agreed program of infrastructure delivery. Contracts would typically extend to several years (for example a regulatory review period) and would be subject to service-level agreements and various performance incentives.

Economies of scale: Any of the above options might confer economy-of-scale benefits and potential efficiencies in terms of combined work reporting centers, common IT systems [such as geographic information systems (GIS) and workforce management systems], vehicle procurement and maintenance, shared human resources (such as back-office staff), and joint supply chains (such as shared groundworks and civil works contractors).[8] There might also be efficiencies gained from a multiskilled workforce whereby staff transferred from both parent organizations are trained to be able to perform operations across the networks of each

6 Customer service-based models are the subject of a dedicated paper in this series.

7 For example, the Federal Trade Commission (FTC) in the United States and the Competition and Markets Authority (CMA) in the UK.

8 There are examples of multi-utility business models, for example through mergers of electricity and water companies.

vector. From a regulatory perspective, this model requires transparent accounting such that respective regulators are able to see that costs are being correctly allocated and apportioned across energy vectors and/or between sectors, preventing cross-subsidies that would undermine regulators' abilities to benchmark performance and business efficiency.

Strategic partnerships: A simpler alternative, avoiding the need for changes in legal ownership, might be for utilities to form partnerships to jointly undertake coordinated energy infrastructure planning and delivery. This might typically involve electricity, gas (natural and/or hydrogen) and heat network operators operating within the same geographic region, and ideally extending to onshore wind, solar PV and BESS developers, and local authorities responsible for spatial planning approvals. Such partnerships could be very effective in creating joined-up, coordinated, vector-optimized regional energy plans, avoiding the pitfalls of undertaking energy planning in vector-specific silos. Additionally, there would be no need for changes in legal ownership or the regulatory framework, with the regional energy plans relying instead on less formal agreements, such as a memorandum of understanding, and an effective multi-vector governance framework.

Business culture: A utility's business culture and appetite for both business growth and risk will determine which of the above options it might consider. An EPRI report, *Toward Net Zero - The Evolving Utility Business Model and Possible Future Scenarios*,[9] suggests that utilities could be differentiated according to where they position themselves on the matrix shown in Figure 6.

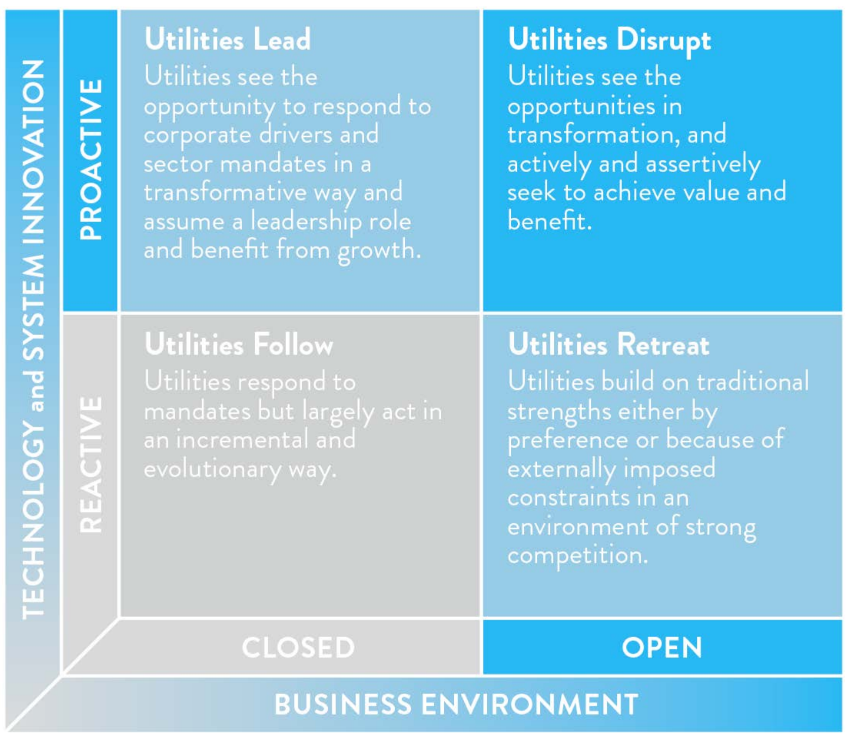

Figure 6. Energy system transformation scenarios for utilities

9 https://www.epri.com/research/products/000000003002025745

The scenarios provide a way to organize and describe the context in which utilities are likely to be required to operate and reveal options for how they might choose to participate, for example:

- **Utilities Follow:** A utility that is positioned in the bottom left **closed-reactive** quadrant of the matrix will generally embrace a business strategy that sustains, rather than grows, its position within the sector. Its focus will be on evolutionary rather than revolutionary opportunities, preferring to adopt a lower-risk strategy by following rather than leading the competition or its peers. In terms of its appetite for pursuing multi-vector opportunities, it is more likely to consider strategic partnerships rather than joint ventures or mergers.
- **Utilities Retreat:** A utility positioned in the bottom right **open-reactive** quadrant will be more open to business opportunities surrounding economies of scale but without extending beyond its comfort zone. For example, an electricity utility might explore economy-of-scale opportunities with a geographically adjacent gas or water utility, such as shared depots and facilities (including vehicle procurement and maintenance and IT and HR services, for example) and shared groundworks staff while retaining a single-vector approach to network planning and management.
- **Utilities Lead:** A utility positioned in the top left **closed-proactive** quadrant will have a greater appetite for higher risk/higher reward opportunities that have the potential for transformational business change rather than simply incremental change. In terms of multi-vector opportunities, this might extend to a joint venture with another utility whereby the management of both companies' network assets is outsourced to a newly formed business-separated asset management company populated with staff transferred from the two parent companies. Both parent companies would retain core management teams to govern the two separate network asset management contracts.
- **Utilities Disrupt:** A utility positioned in the top right **open-proactive** quadrant is more likely to embrace opportunities surrounding mergers and acquisitions with utilities operating in different vectors. While this entails greater risk in terms of creating a new multi-vector management team and merging workforce skills, it also provides the opportunity to exploit greater economies of scale in the longer term, including through integrated system planning and supply chains. Of all the multi-vector opportunities, this option presents the greatest challenge in terms of overcoming regulatory barriers since regulators would need to create new multi-vector licenses and accept that, from a price control review perspective, it would not be possible to separate out the company's operating costs on an individual vector basis.

MULTI-VECTOR BENEFITS FOR CUSTOMERS

While the above discussion focuses on multi-vector business opportunities for utilities, there are several potential benefits to customers including the following:

- The potential for multi-vector service opportunities, for example a service company supplying a domestic hybrid heating package including a heat pump/gas boiler combination, with the customer paying a single service charge rather than two sets of energy charges.
- For new housing or commercial real estate developers, the need to engage only with a single company for design and installation of the associated gas, electricity, and/or heat network infrastructure, as well as for network connections to properties. Further synergies would be possible where the business model includes other vectors such as telecoms and/or water as well as energy vectors.
- The potential for all customers to benefit from lower network access and use-of-system charges arising from the economies of scale associated with multi-vector partnerships, joint ventures, and mergers.

CREATING AN ENVIRONMENT FOR MULTI-VECTOR BUSINESS MODELS

A multi-vector business model requires coordination of both energy infrastructure planning and delivery at national and regional levels. Creating an environment conducive to the emergence of multi-vector business models is therefore dependent on a clear and committed national energy strategy, an agreed transition pathway, and a coordinated delivery plan. Without these elements, the appetite for new multi-vector business models will be limited due to uncertainty and hence lack of investor confidence. To that end, the whole energy system framework described in this paper could be applied to the creation and delivery of a national spatial, temporal energy plan (STEP)[10] based on systems thinking, setting out not only what needs to be built and where in terms of energy infrastructure, but also by when. That in turn would establish a foundation for development of state and regional STEPs, each addressing place-specific opportunities and challenges while remaining aligned to national strategic energy objectives.

Strategic Oversight

Given the necessary attention to the described drivers and enablers, a STEP would provide the essential direction and business environment for the creation of new multi-vector business models. The creation of a STEP suggests the need for an "Energy Systems Architect" function overseeing the coordination of central, state, regional, and local energy planning to achieve national objectives surrounding energy security, affordability, and sustainability, while capitalizing on subnational opportunities that might otherwise be opaque from a purely centralized approach to strategic energy system planning. This is particularly relevant to multi-vector business models that are more likely to succeed if customized to take advantage of regional circumstances.

By way of example, in Great Britain, a new Electricity Bill makes provision for the establishment of an Independent System Operator and Planner (ISOP) as a public body regulated by the regulator Ofgem. A new organization, currently designated as the National Energy System Operator, created from the current Electricity System Operator, will fulfill this role and initially have responsibility for the creation of a Central Strategic Network Plan for both electricity and gas, as well as for establishing Regional Energy Strategic Planners (RESPs). The expectation is that the ISOP role will ultimately extend to all energy vectors and interactions across interdependent sectors with responsibility for a national Strategic Spatial Energy Plan (SSEP) while RESPs will be accountable for creating and delivering vector-optimized Regional Energy Strategic Plans. The RESP forums would create an ideal framework for the above-mentioned utility partnership model.

10 There is also a case for an international STEP where energy systems extend across national borders (for example, subsea interconnectors and interconnected transmission systems) or where there are shared dependencies on fuel sources.

CONCLUDING OBSERVATIONS

Existing multi-vector business models—such as energy retailers supplying both electricity and gas, including through dual-fuel tariffs; business models that span energy vector networks (for example electricity, gas, and/or heat networks); or business models that cross sectors (for example electricity and water)—have been successful in delivering economies of scale. However, they have been unable to fully exploit the synergies of coordinated multi-vector energy systems in terms of energy conversion, arbitrage, and storage, as well as hybrid/dual-fuel applications.

Energy in Transition

Energy systems are undergoing a period of transition from fossil fuels to renewables and carbon-neutral sources as part of an overall global strategy to decarbonize both energy supply and demand. Drivers for energy transition include sustainability (reducing dependency on depleting oil and gas reserves) and energy security (reducing dependency on imported fossil fuels as a hedge against geopolitical uncertainty). However, the major global driver of this transition is in support of commitments to reduce greenhouse gas emissions and achievement of net-zero targets. This will inevitably lead to a transition away from the use of unabated fossil fuels and toward the emergence of carbon-free alternatives such as hydrogen or limited use of natural gas with carbon capture. This in turn will require a multi-vector approach to energy policy.

A System of Systems

Effective and economic energy transition requires that energy be considered from a whole energy perspective and as a complex integrated system of systems with many interdependencies and potential interactions, both within and between energy vectors. The increasing transition from fossil fuels to low- or zero-carbon alternatives for both energy supply and demand gives rise to a greater degree of interaction between energy vectors. This interaction needs to be optimized across all timescales: investment planning, operational planning, and real-time operations.

A Whole System Approach

A whole energy system is defined in terms of its composition and boundaries, in terms both of interactions within the energy system and, from a wider economy perspective, interactions with interdependent sectors. This requires the application of systems thinking to the overall design of the energy system, extending to interdependent sectors as well as to the drivers and enablers of the low-carbon energy transition, while embracing national, state, regional, and local perspectives. The overall objective of a systems approach is coherence by design, embracing energy transition through understanding the interactions within and beyond the energy system.

New Multi-Vector Business Models

The increasingly complex framework of cross-vector and inter-sector interactions creates an opportunity for new business models that are able to capitalize on the benefits of a coordinated multi-vector and inter-sector approach, in preference to perpetuating single-vector business models that, as a consequence of their inherent design limitations, are unable to fully exploit the synergies of multi-vector models. Such business models, potentially based on utility mergers or joint ventures—or simply partnerships—will be more complex but better aligned to the goals of energy decarbonization, affordability, and security of supply. Whichever model is adopted, it will be more effective if operating within both a national and regional energy strategic planning framework.

Business Risk

While there are potential benefits to utilities in adopting a multi-vector business model in terms of economies of scale and potential efficiencies arising from shared IT systems, human resources (including multiskilling), and supply chain optimization (for example shared groundworks and civil works contractors) there is also a need for utilities to consider the costs and risks of transitioning to a multi-vector business model. Albeit efficiencies can be expected in the longer term, depending on which model is adopted, there might be significant implementation costs involved in adopting a multi-vector model, including merging IT systems (such as asset management, GIS and workforce management systems) and costs of multiskilled workforce training. Risks include diversion of management attention during the transition period, potentially leading to reduced operational efficiency, customer service, or even safety performance, while employees are gaining new skills and experience with new energy vectors.

Customer Benefits

The creation of multi-vector utilities gives rise to potential customer benefits in terms of opportunities for new cross-vector service models rather than simply delivering energy as a commodity. Multi-vector utilities should also be able to offer reduced access and use-of-system charges arising from economy-of-scale efficiencies through partnerships, joint ventures, and mergers. For developers or industrial/commercial customers seeking new network connections, the application process is greatly facilitated through a single point of contact with a multi-vector energy infrastructure company that can design and deliver an integrated energy infrastructure for the development or project.

Creating the Right Business Environment

Applying a whole energy system approach will entail many interactions and interdependencies both between energy vectors and between the energy sector and interdependent sectors. For these interactions and interdependencies to be implemented successfully, attention will need to be given to associated drivers and enablers, such as energy policy, markets, and regulation. A clear and committed energy strategy is essential to creating the appetite for new business models. A national spatial, temporal energy plan (STEP) setting out not only what needs to be built and where in terms of energy infrastructure, but also by when, will provide the essential direction and business environment for the creation of new multi-vector business models. Having established a national STEP as a foundation, coordinated regional energy strategic planning will then be key to ensuring the optimum energy vector mix to meet each region's needs while also delivering national energy objectives. Multi-vector business models are more likely to succeed if customized to take advantage of regional circumstances and the geographic footprints the utilities serve, and if subject to an effective governance framework extending to onshore wind, solar PV, and BESS developers, and local authorities responsible for spatial planning approvals.

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EPRI CONTACT

NEIL HUGHES, *International Executive Director*
+44 7979 708360, nhughes@epri.com

For more information, contact:

EPRI Customer Assistance Center
800.313.3774 • askepri@epri.com

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