What in the world is infrastructure?

The definition is crucial: if we don't know what it is we're talking about, there is no way we can confidently invest in infrastructure, writes **Jeffrey E. Fulmer**

GOVERNMENTS ARE PROJECTED to spend about three percent of the world's GDP on infrastructure in 2009 to meet the needs of expanding populations and to desperately attempt to prop up crumbling bridges, highways, water pipelines, and other system components. The investment community is establishing evermore equity and debt investment vehicles targeting global infrastructure. Yet, when someone mentions *infrastructure*, we reply out of necessity, "How are you defining *infrastructure*?"

Attempts to define *infrastructure* have been made by national agencies, provinces and states, municipalities, professional and trade organisations, the financial community, academia and, of course, dictionaries. Inconsistencies and sector-specific biases abound, but common threads run through the myriad of definitions. Nearly all mention or imply the following characteristics: interrelated systems, physical components and societal needs.

Some sample definitions include:

The infrastructure supporting human activities includes complex and interrelated physical, social, ecological, economic, and technological systems such as transportation and energy production and distribution; water resources management; waste management; facilities supporting urban and rural communities; communications; sustainable resources development; and environmental protection (American Society of Civil Engineers, 2009).

The essential facilities and services that the economic productivity of a community or organisation depends on. As a real return asset class, infrastructure includes those assets that are involved in the movement of goods, people, water, and energy (Weisdorf, 2007).

Infrastructure assets are the physical structures, facilities, and networks that provide essential services to the public. These assets include transportation structures (roads, bridges, tunnels, railways, airports, and seaports), energy and utility companies, communication entities, and social services such as educational facilities and hospitals (Chambers, 2007).

Certain definitions have been so broad as to include people as infrastructure. Reimut Jochimesen's 1966 book, *Theorie der Infrastruktur, Grundlagen der marktwirtschaftlichen Entwicklung*, focused on infrastructure's role in the development of a market economy. He defines infrastructure as the sum of the material, institutional, and personal foundations of an economy that contribute to realising the assimilation of factor remuneration, given an expedient allocation of resources. Jochimesen uses the term "personal infrastructure" to encompass the number and qualities of people in the market economy.

A practical definition of *infrastructure* is sought that satisfies standard uses of the term by integrating the common themes of systems, physical assets, and societal needs. Additionally, a listing of primary infrastructure components is thought useful in assisting infrastructure-related discussions.

INTERRELATED SYSTEMS

Infrastructure systems or networks of interrelated components are the analogous arteries and veins attaching society to the essential commodities and services required to uphold or improve the standards of living. They are often monopolistic in terms of local or regional control of a good or service and typically involve substantial capital investment. Providing access to water supply and treatment, electric power, fuel, transportation, and communications are among the most fundamental of societal services. Each of these services is characterised by expansive systems that link supply and demand and involve interconnected assets performing different functions and enabling the operability of their respective networks.

Primary infrastructure sectors certainly include electric power, oil and gas, potable and waste water, transportation, and communications. A defensible, but less obvious list of sectors includes food and agriculture, chemical, financial, and social infrastructure. Although embraced by the investment community, social infrastructure is perhaps the most difficult to defend. Its physical components include schools, courthouses, prisons, and hospitals. Networks for these social assets, however, are almost entirely non-physical and can be only loosely described by educational, judicial, penal, and health care systems. Having understandably attractive investment characteristics that include long-term contracts and fee-based structures, social infrastructure is similar to other physical assets that are broadly not termed infrastructure; e.g., church buildings, condominium complexes, and entertainment venues. These "systems" also attract investment and satisfy certain societal needs.

An electric power grid is a system of power plants, substations, power lines, and control centres that are more specifically described as interconnected generators, transformers, transmission lines, buses, circuit breakers, reclosers, protective relays, switches, voltage control devices, distribution lines, and computers. Each component or collection of components (e.g., the varied subcomponents of a substation) plays its operability role through

accepting inputs and yielding outputs. A substation's input is voltage at one level, and its output is voltage at another level.

Natural gas systems encompass wells, gathering pipelines, sales meters, compressors, processing plants, natural gas liquids (NGL) pipelines, fractionation plants, transmission pipelines, control centers, market hubs, storage facilities, city gates, distribution pipelines, and a multitude of meters, valves, and emergency shut-off mechanisms. These physical components are connected and interrelated to form a functioning system.

PHYSICAL COMPONENTS

Infrastructure assets, as defined herein, are those physical links and nodes of networks. They can be built, touched, enabled, or disabled. The assets are like the individual links in a physical chain that have shared-dependency on each other to provide an overall function. In the absence of redundant links or workarounds, a broken link weakens or disables a portion (if not all) of its associated infrastructure network.

The commodities that flow through the infrastructure are not a part of the infrastructure system. Some physical assets rely on non-physical services; e.g., the transmission of voice and data packets integral to communication networks. These "invisible components" are no more an infrastructure asset than is the electric power flowing through transmission lines, crude oil flowing through pipelines, or the influent flowing into a sewage treatment plant. Infrastructure systems and their physical components enable the flow of commodities and services but can be either physically or financially sensitive or insensitive to variations in the amount of commodities and services being conveyed.

Supporting components are integral to each of the primary infrastructure components. As an example, a seaport usually includes most, if not all of the following supporting infrastructure components: wharfs, berths, warehouses, fixed cranes, container yards, fuel storage tanks and pipelines, weighing machines, conveyor belts, and railhead. A natural gas liquids fractionation plant includes a control center; pipelines; manifolds; chillers; demethaniser, deethaniser, depropaniser, and debutaniser columns; storage vessels; and commonly rail and/or barge offloading facilities.

SOCIETAL NEEDS

While interrelated systems and physical components are essential infrastructure traits, these two characteristics by themselves do not adequately define the term. To be characterised as *infrastructure*, the networked assets must be designed to address a societal need.

Infrastructure systems are costly and their focus is not on individuals, segregated groups, or independent companies, but on broader

Sector	Function	Primary Components
ELECTRIC POWER	Power Generation	Coal Power Plants Nuclear Power Plants Natural Gas Power Plants Hydroelectric Power Plants (Dams, Pump Storage, and Run-of-River) Fuel Oil Power Plants Dual-Fired Power Plants Alternate/Renewable Energy Power Plants Distributed Power Plants Back-up Generators Power Plant Substations
	Power Transmission	Transmission Lines and Towers Transmission Substations DC Converter Stations Regional Control Centers
	Power Distribution	Distribution Lines Distribution Substations Step Down Transformers
OIL AND GAS	Exploration and Production	Offshore Drilling and Production Platforms Subsea Facilities Permanent Onshore Drilling Facilities Wells (Production, Injection, Observation, and Disposal)
	Oil and Gas Gathering and Separation	Crude Oil Gathering Pipelines Gas Oil Separation Plants Tank Batteries (Field Seperation and Storage) Crude Oil Lease Automatic Custody Transfer Units Gas Gathering Pipelines and Compressors Field Gas Processing Plants (Dehydration, Sweetening, and Nitrogen Rejection) Gas Sales Meters
	Oil Storage, Refining, Transport and Distriburion	Bulk Storage Facilities (Terminal, Refinery, and Pipeline Breakout) Offshore Mooring Systems Underground Crude Storage Refineries Oil Main Pipelines and Interconnections Pumping Stations Control Centers Truck and Rail Racks
	Natural Gas Processing, Transport, and Storage	Gas Processing Plants NGL Fractionation Plants Gas Transmission Pipelines and Interconnections Transmission Compressor Stations Control Centers Natural Gas Market Hubs Natural Gas Storage Facilities City Gates and Distribution Pipelines LNG Trains and Regasification Facilities LPG/Propane Interconnected Assets
POTABLE AND WASTEWATER	Water Supply, Storage and Treatment	Raw Supply Assets (River, Lake, Spring Inlets, and Wells) Raw Water Storage Assets (Reservoirs and Tanks) Desalination Plants Water Treatment and Filtration Plants Finished Water Storage Assets (Towers, Clearwells, and Standpipes)

society. A family's home is likely the most important structure to them, but it lacks scale, societal dependency, and it is not a component of a network. A company does well to analyse its critical systems and infrastructure dependencies, but this, too, is a myopic use of the term and represents a set of priorities not shared by the surrounding community. A company's key facility may be of some concern to people beyond just the company's owners and employees, but it cannot compare to the local residents' shared dependency on local electric power and water distribution systems. These essential systems rank high in priority for everyone in a community and demonstrate convergence of their shared reliance.

Society's dependency on *infrastructure* is most clearly evidenced in the aftermath of service disruption. For example, Hurricane Katrina caused severe infrastructure damage along the US Gulf Coast when it made landfall in August 2005. Electric power, oil and gas, water, transportation, and communication services were all disrupted and commodity flow impacts were felt along the entire East Coast and parts of the Midwest, with the financial impact even more far reaching.

Infrastructure needs are especially pronounced in emerging economies whose citizens struggle to gain access to even the most basic life-supporting commodities and services. Beyond the developed world's need to replace or repair crumbling infrastructure, these countries need to build systems to initiate service in rural areas and vastly expand service in their growing urban communities.

Sector	Function	Primary Components
POTABLE AND WASTEWATER (CONTINUED)	Water Delivery	Water Tunnels Aqueducts Transmission Mains Pumping Stations Pipeline Interconnections Distribution Mains Service Pipelines Control and Monitoring Stations
	Wastewater Collection,	Sewer Inlets and Mains (Sanitary, Storm and Combined)
	Treatment, and Discharge	Influent Storage (Tanks, Pits, Ponds and Basins) Waste Water Treatment Plant Pumping and Discharge Facilities Control and Monitoring Stations
TRANSPORTATION	Road Transport	Roads and Highways (including Toll Roads) Bridges (including Toll Bridges) Tunnels (including Toll Tunnels) Operations and Traffic Management Centers Border Crossing Facilities Truck Terminals
	Rail Transport	Rail Cars (Freight and Passenger) Tracks Bridges Tunnels Yards Passenger Stations Operation Centers
	Waterway Transport	Locks and Canals Dams Docks Navigation Facilities
	Sea Transport	Seaports (Shallow and Deep Draft)
	Air Transport	Airports (Certified, Non-Certified, and Military) Airstrips and Airfields Heliports Spaceports Air Traffic Control and Navigation Facilities
	Mass Transport	Subway Systems Commuter Rail Systems (Heavy and Light Rail) Bus Systems Tramway and Ferry Systems
COMMUNICATIONS	Wireline Services	End Office Switching Facilities Access Tandems Cables (including Submarine Cables) Submarine Cable Landings Telecom Hotels Interexchange Carrier Points of Presence Carrier Data Centers Internet Service Provider Points of Presence Internet Service Provider Routers
	Cable Services	Cable Broadcast Provider Headquarters Headend/Distribution Hubs Cables
	Wireless Services	Cell Towers Base Transceiver Stations Base Station Control Stations Mobil Switching Offices
	Broadcast Services	Television/Radio Network Headquarters Local Broadcast Centers Transmitter Sites
	Data Processing/ Network Management	Data Centers Operation Centers

CONCLUSION

Encompassing all things to all people is hardly a useful way to define *infrastructure* – clouding investors, governments, and their citizens' ability to understand, advocate, and direct capital toward durable, networked assets with widespread societal benefits. Primary infrastructure components are generally monopolistic in nature and require large financial commitments for their development, repair and replacement. They can be built, touched, enabled, disabled, and function together to form interrelated, dependent systems that deliver needed commodities and services to society. In doing so, they facilitate economic productivity and promote a standard of living. *Infrastructure* can then be more concisely defined as "*The physical components of interrelated systems providing commodities and services essential to enable, sustain, or enhance societal living conditions.*" ◘

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