Renewable Energy Systems as an example of layered Systems of Systems

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Abstract

The energy transition required to achieve the Paris climate agreement impacts the entire energy system. The energy system consists of many systems and an infrastructure connecting these systems. How can (Systems of) Systems Engineering assist in this complex transition? In this presentation, we will use a number of concrete examples to explore the systems engineering role and methods for this complex and dynamic application.

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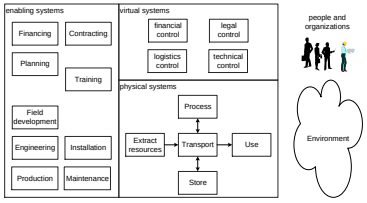
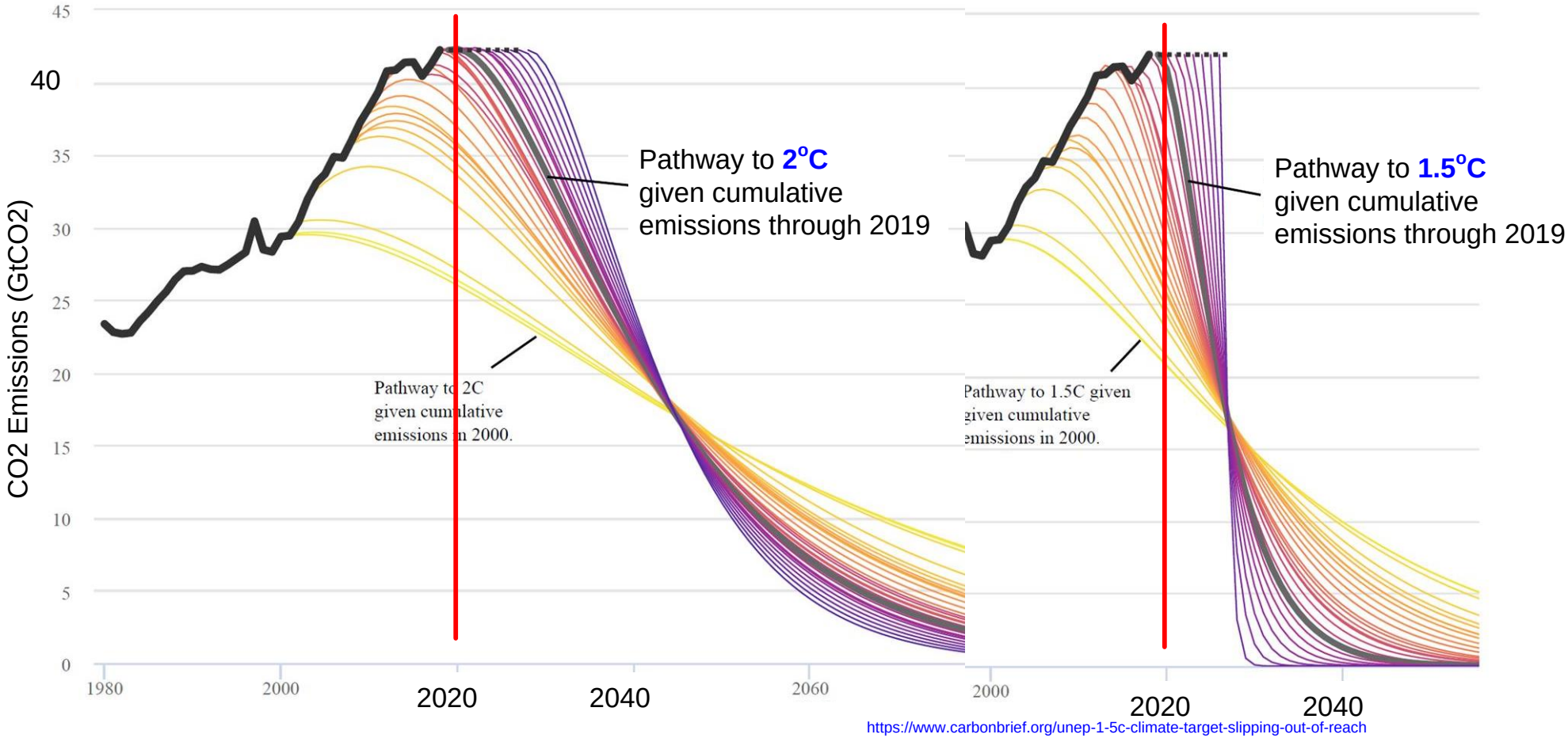


UN Sustainability Development Goals

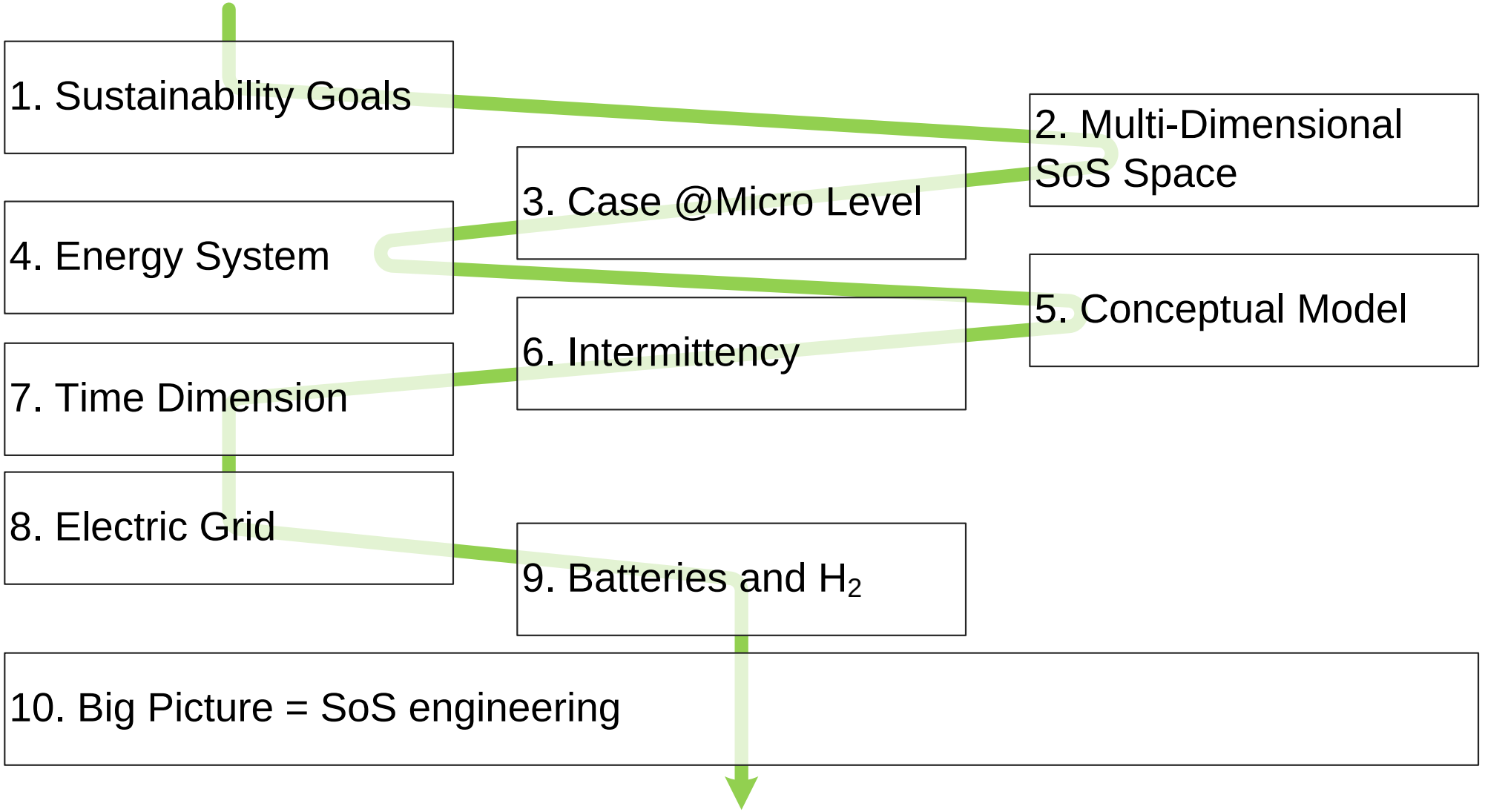
Time is Running Out



https://www.carbonbrief.org/unep-1-5c-climate-target-slipping-out-of-reach

Source: Historical CO2 emissions from the Global Carbon Project. 1.5C carbon budgets based on the IPCC SR15 report. Original figure from Robbie Andrews. Chart by Carbon Brief using Highcharts.

Figure Of Contents TM



Dimensions of Energy Systems

Sustainability Goals

Geographic (from device to global)

Function (from extraction/harvesting to use)

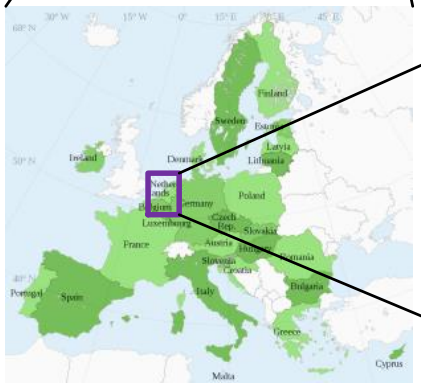
Socio-economic and technical (from goal to operation)

Time (from subsecond to century)

From Macro to Nano

Global (**Macro**)

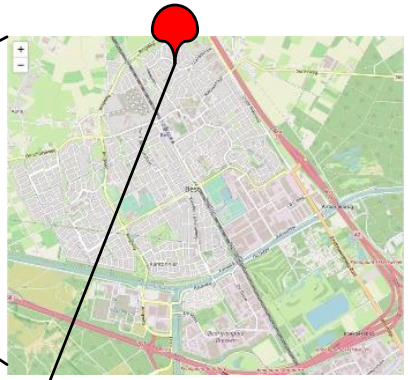
EU



Province Noord Brabant

(**Meso**)
The
Netherlands

Town Best



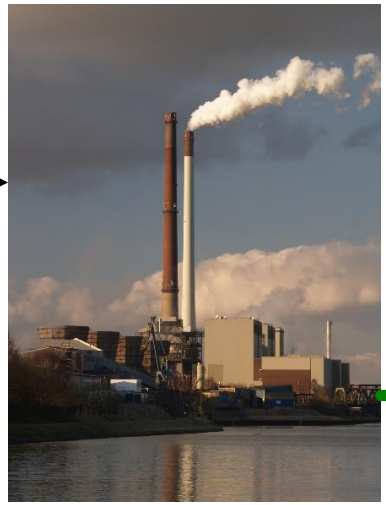
Gerrit's house
and
systems
(**Micro**)

Technology
(**Nano**)

Traditional Fossil Energy Systems

coal mine

coal train



coal power plant

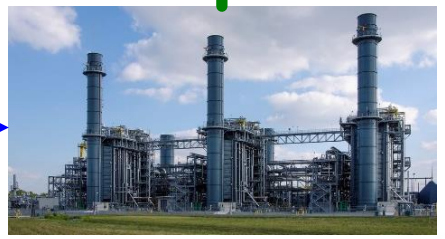
High Voltage network

oil and gas FPSO

subsea processing system

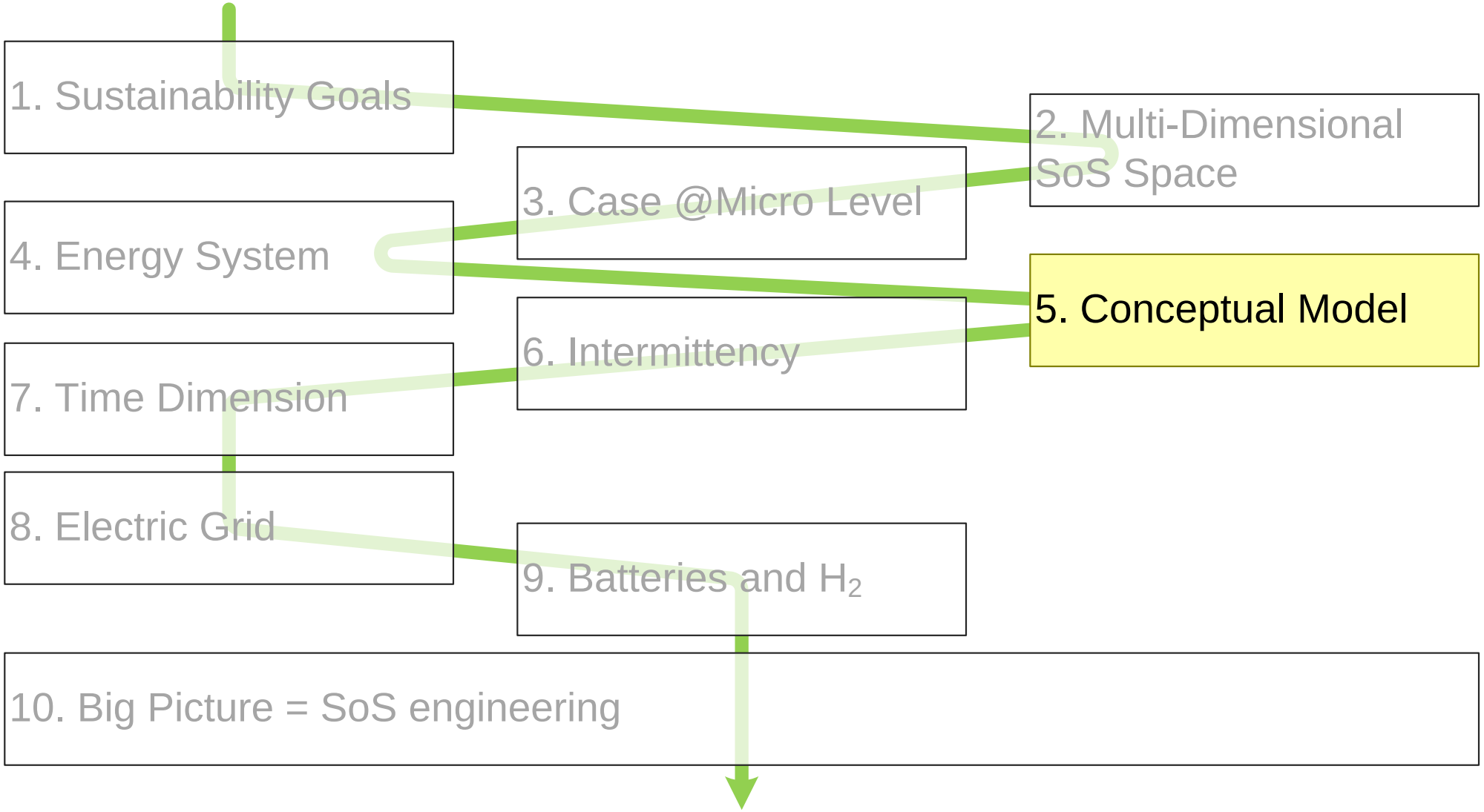
LNG tanker

LNG storage tank



gas power plant

Conceptual Modeling



Simple Functional Model

coal mine

coal train

coal power plant

physical systems

Process

Extract resources

Transport

Use

Store

oil and gas FPSO

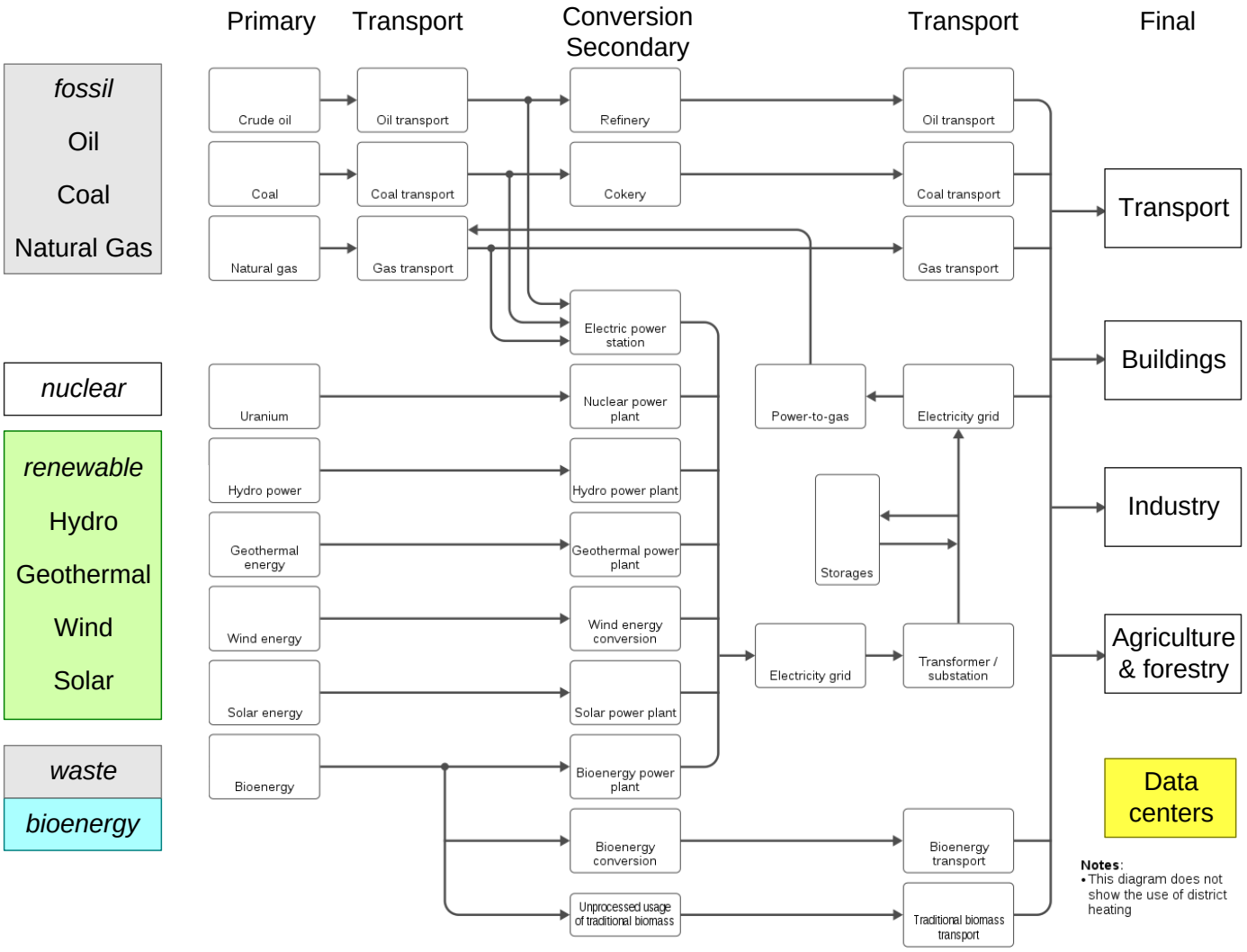
gas power plant

subsea processing system

LNG tanker

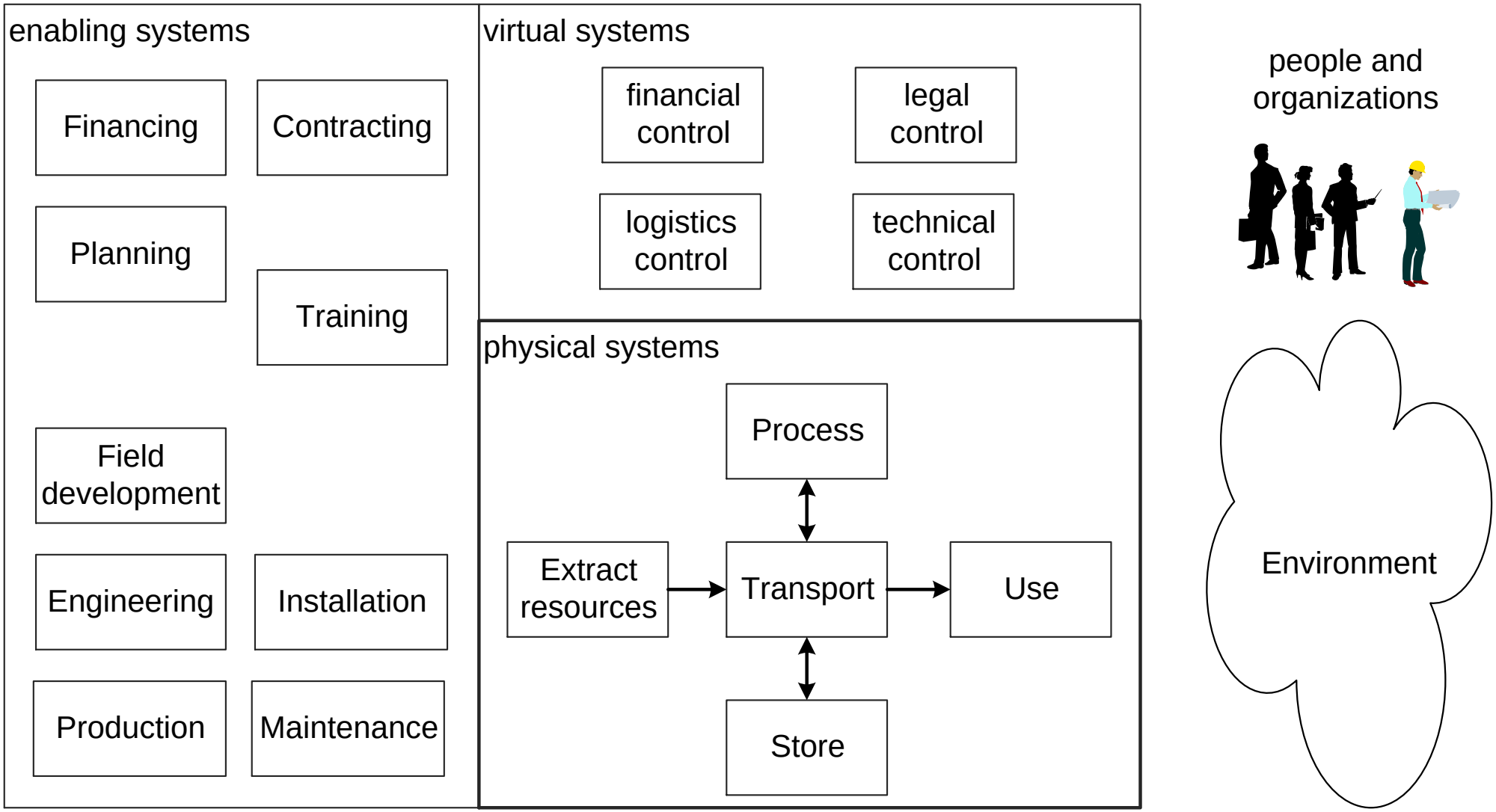
LNG storage tank

Wikipedia Energy Model

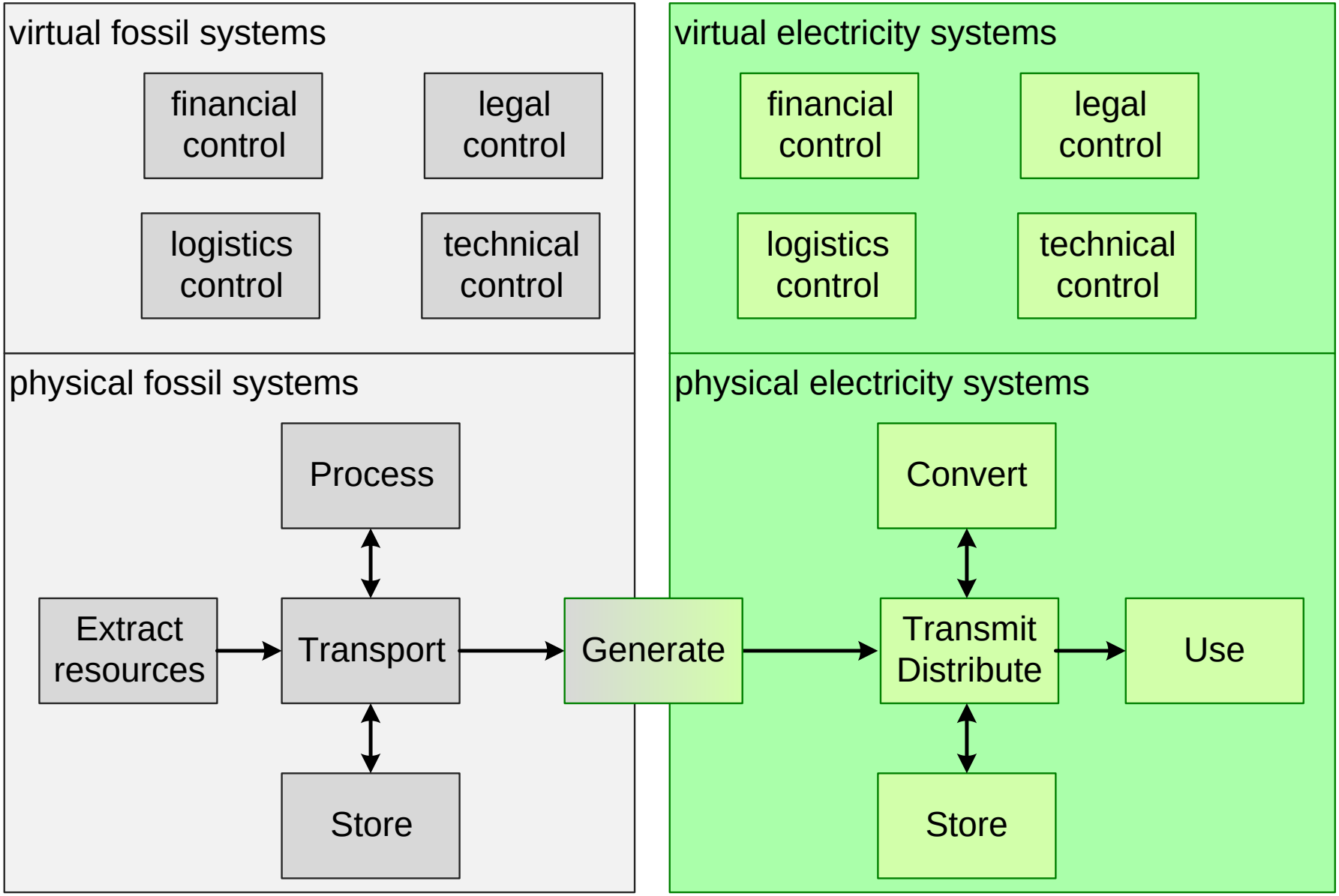


based on: https://en.wikipedia.org/wiki/Energy_system This file is licensed under the Creative Commons Attribution https://en.wikipedia.org/wiki/en:Creative_Commons -Share Alike 4.0 https://creativecommons.org/licenses/by-sa/4.0/deed.en International license.

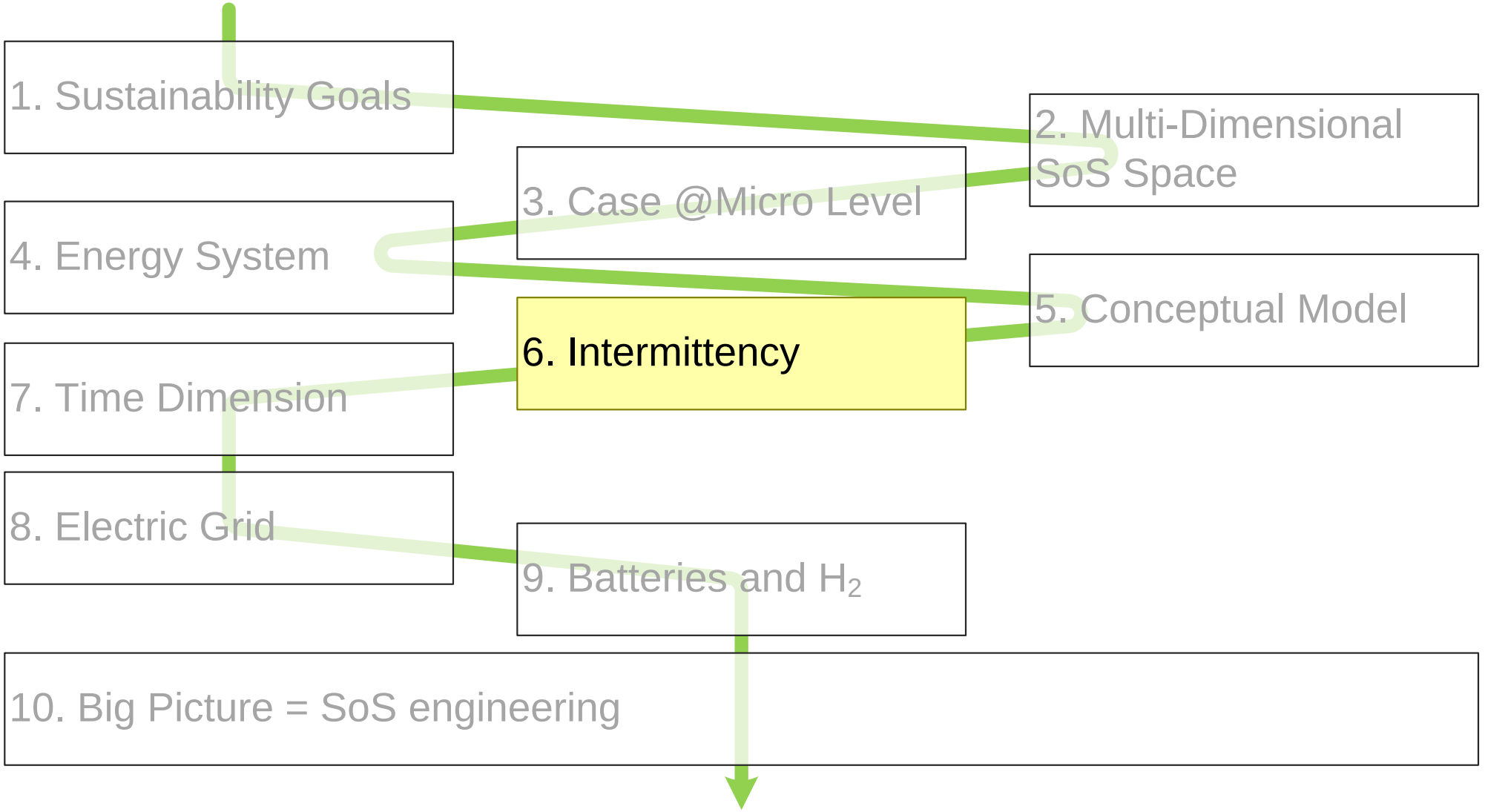
More than Physical Systems



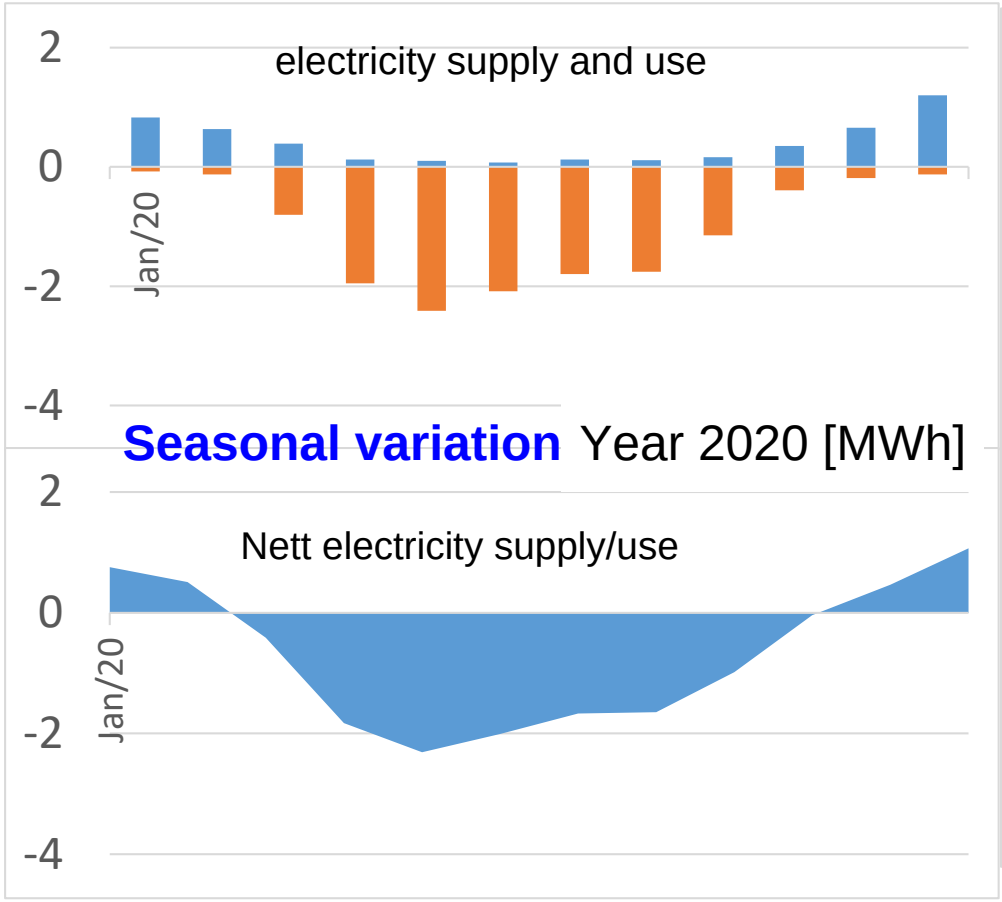
Toward Electricity

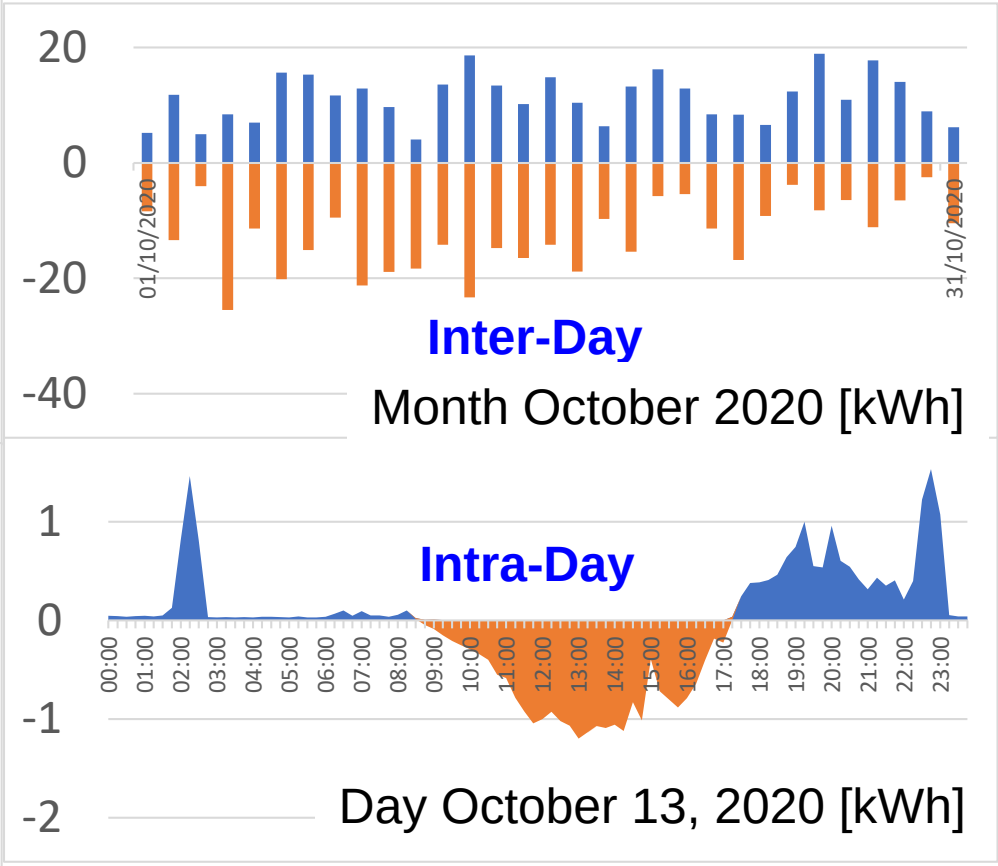


Renewable Energy Introduces Intermittency

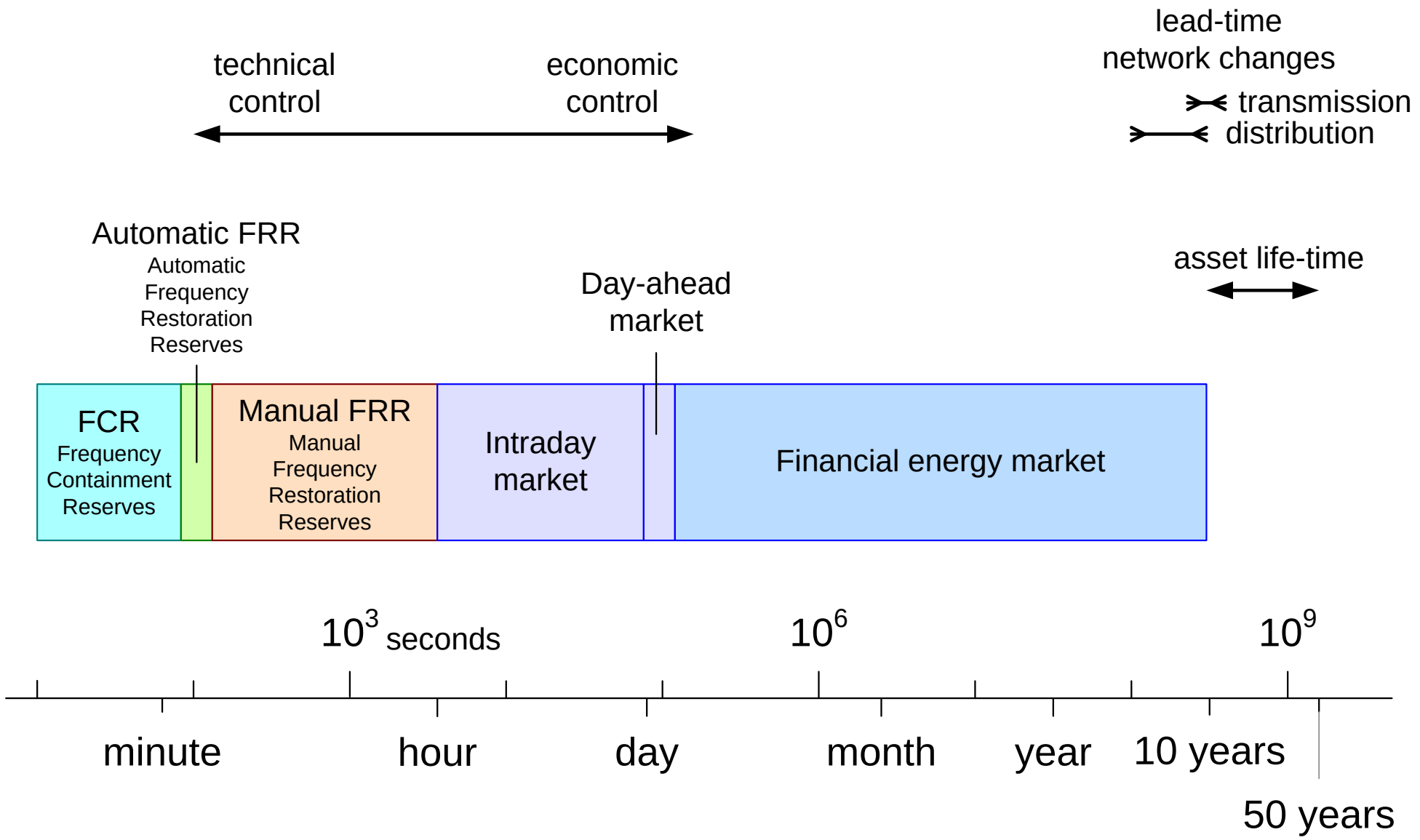


Variations at Micro-Level

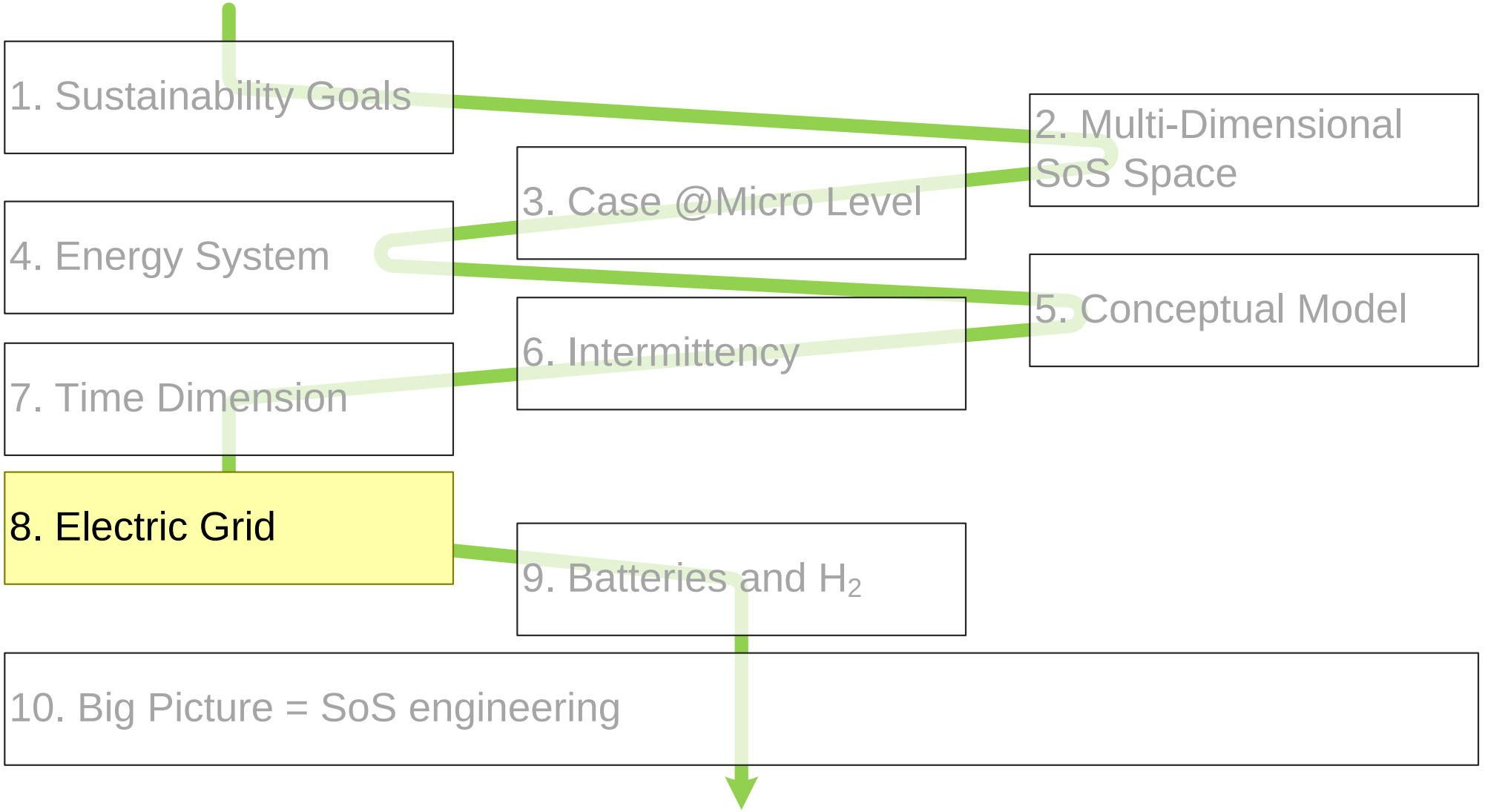




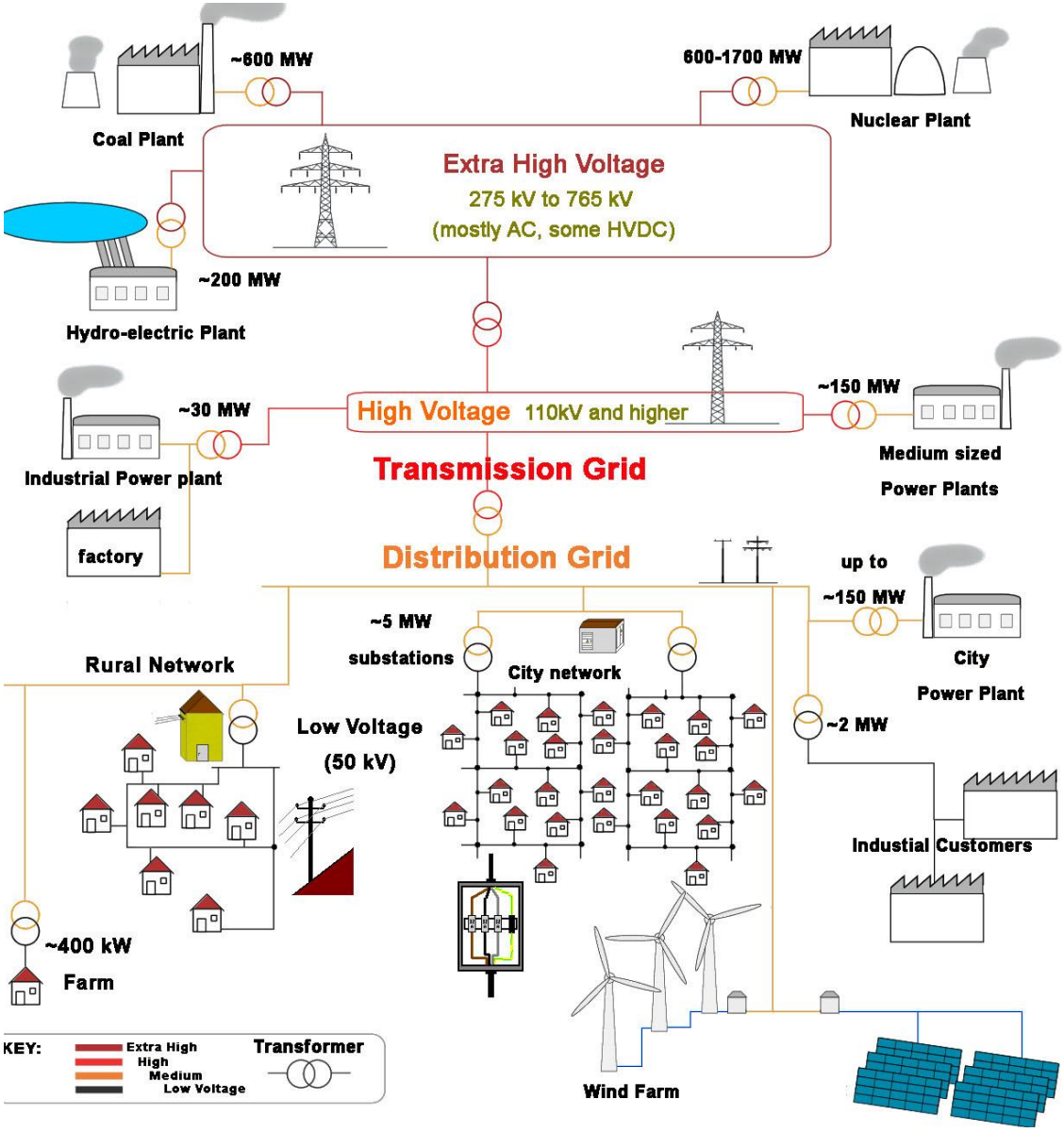
Dynamics on a Logarithmic Time Scale



Zooming in on Electric Grid



Wikipedia Electric Grid



from: https://commons.wikimedia.org/wiki/File:Electricity_grid_schema-_lang-en.jpg
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Large
High Power 100s MW
High Voltage up to ~1 MV
High cost G$

Transmission Grid

Distribution Grid

Neighborhood Grid?

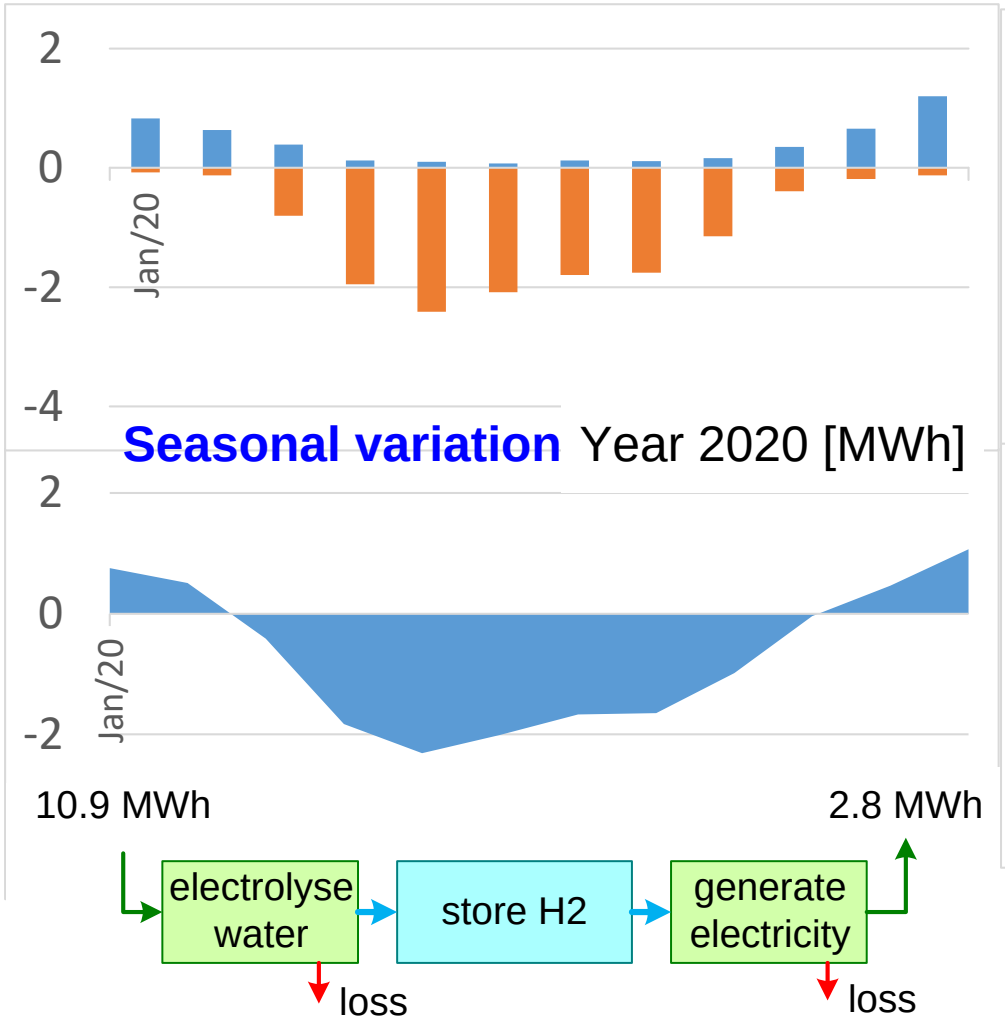
Home Grid

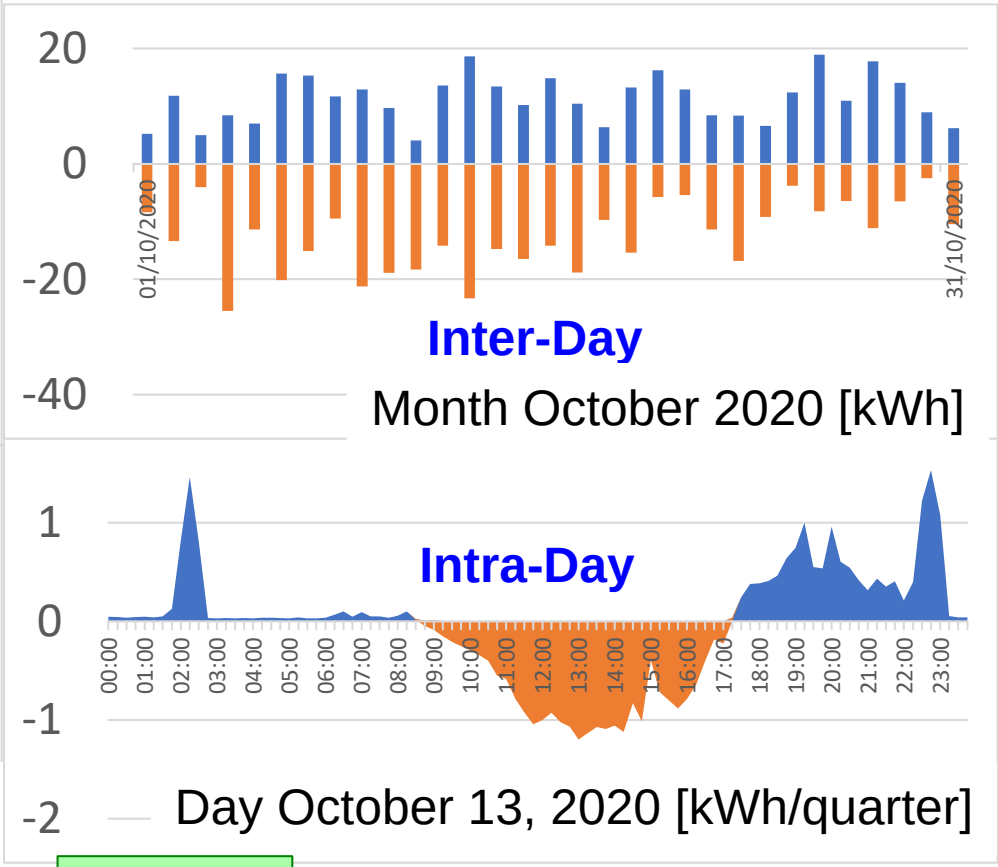
Small
Power few to 100s kW
Voltage up 0.24..50 kV
10s..100s k$

How to Keep the Grid Stable?

- Geographic smoothing — **Transport** (distribution, transmission)
- Time smoothing — **Store, retrieve**
- Demand control — **Control, incentivize**
- Over dimensioning — **Curtail**
- Add generation capacity — **Bio Mass**, **Gas or worse**

Micro Level Storage

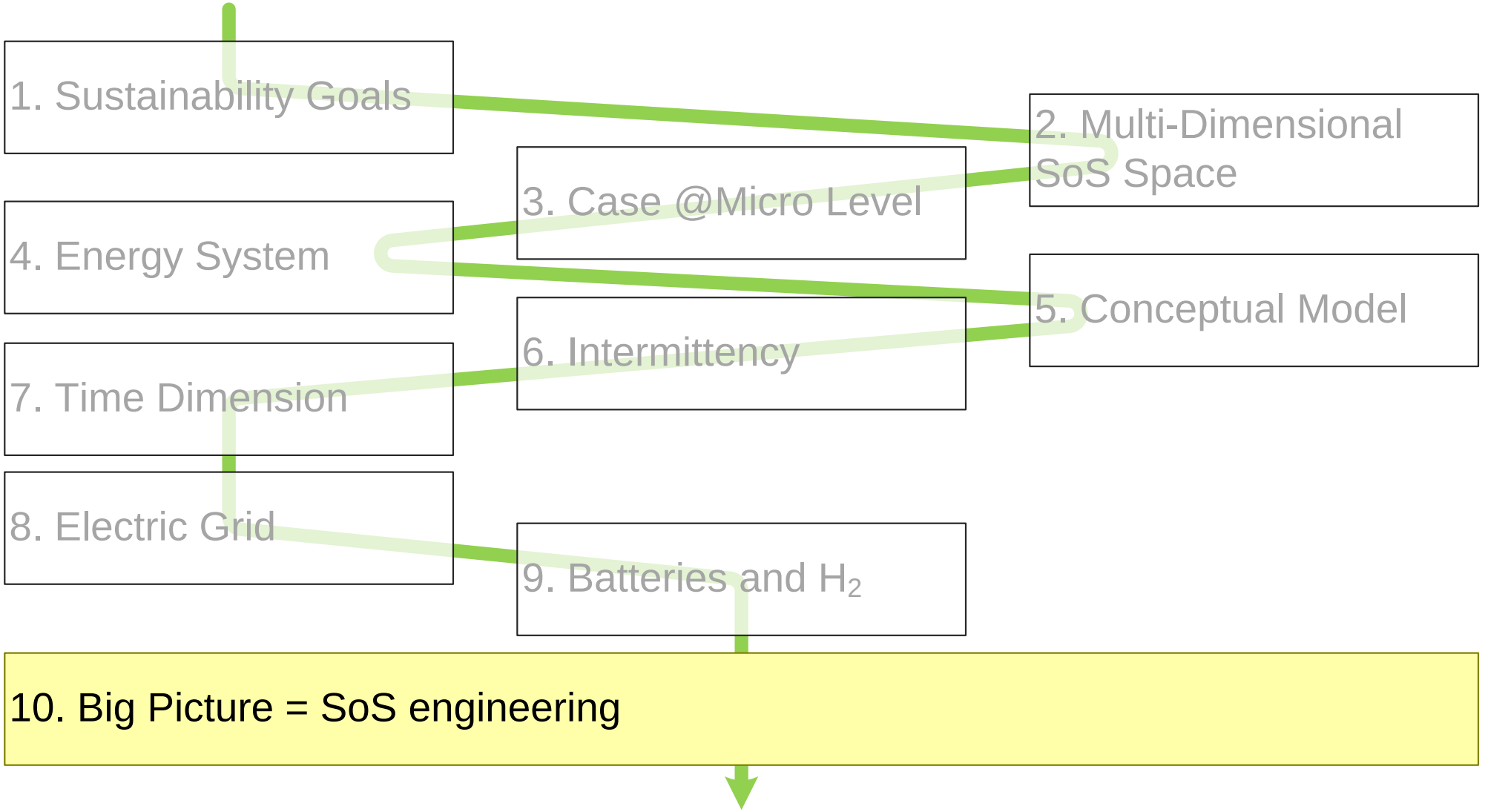




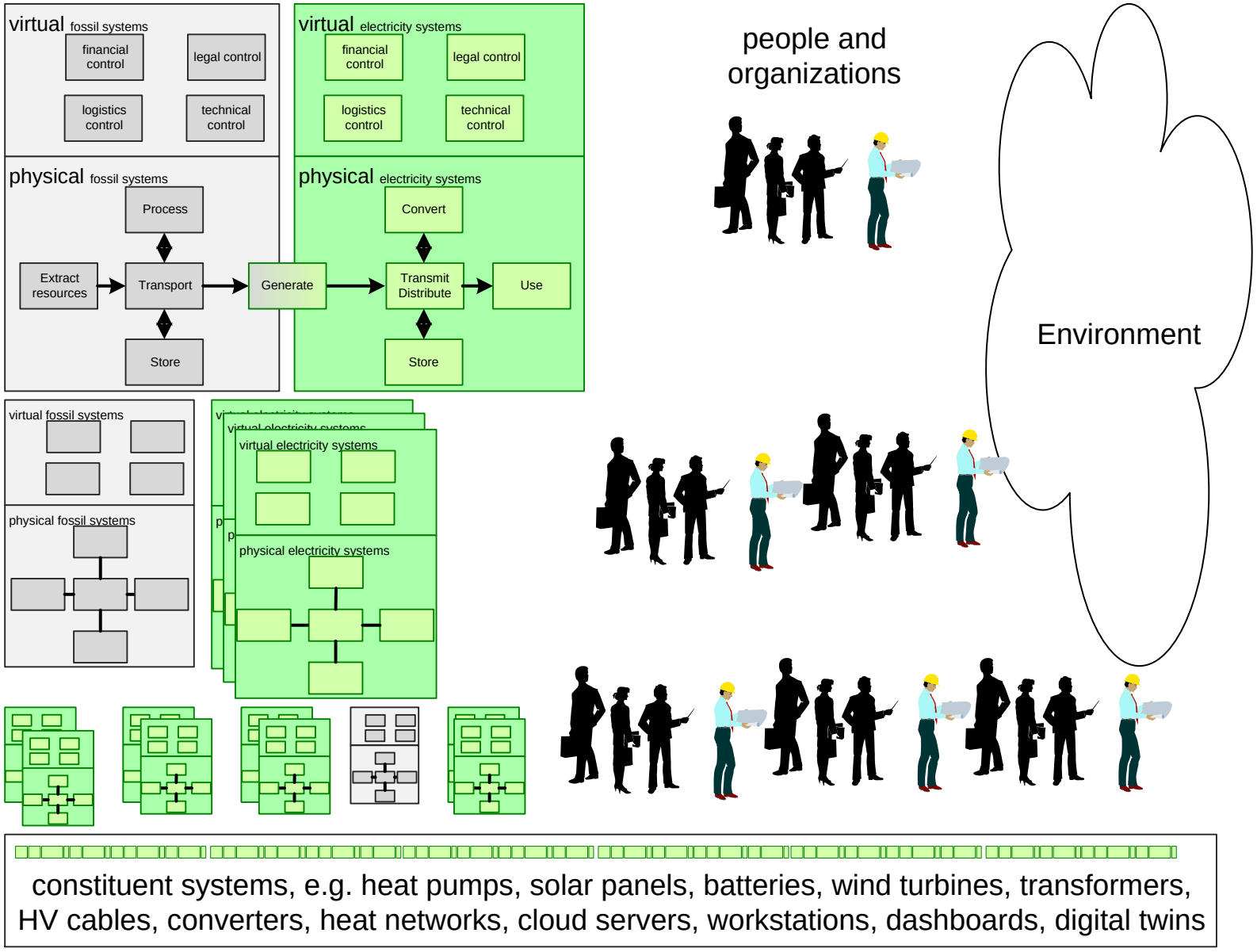
battery 20..30 kWh

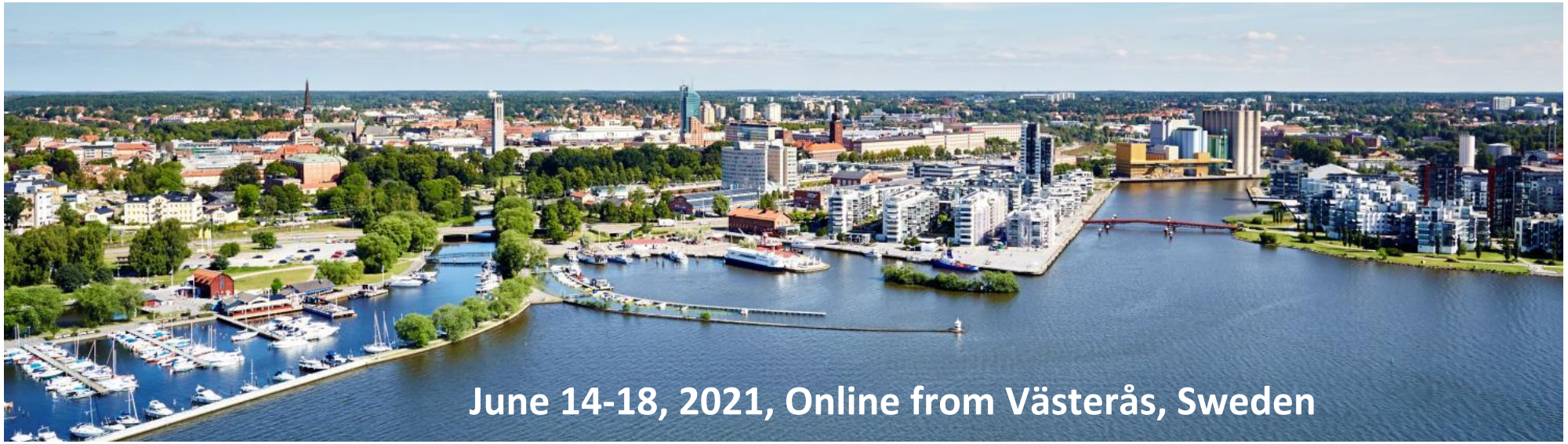
increases self-consumption 1.4 MWh

Systems of Systems Engineering



Layers of SoS





16th Annual System of Systems Engineering Conference

Conference theme: Autonomous Cyber-Physical Systems of Systems

http://sosengineering.org/

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Key dates for submissions

Technical papers &panels: **Jan. 31, 2021**

Notification, papers &panels:**March 14 , 2021**

Final manuscript: **April 11, 2021**