Nazarbayev University Kazakhstan
Energy Transitions:
Exploring the nexus of Sustainability, Economy and Climate

Innovations in Electricity generation

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In 2022, electricity covered 20.4% of commercial energy consumption. In carbon free energy systems, this share should approach 100%.

Overview:
- **Basic information about electricity**
- **Electricity's central position in a modern energy economy**
- **Transformation for escaping climate collapse**
- **From Vertical Integration to Unbundled systems**

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Basic information about electricity for laymen on this topic

1880s: Electricity appeared in the capitals of industrializing nations

As providing light and power without fire and emissions, it was highly willed energy.

However, its expansion went slow, because of inherent and technical characteristics:

- **Electric current is generated from other energy currents with specific technology & losses**
- **Electricity is transmitted via wires to specific end-use appliances**
- **Huge investments and poor efficiencies of thermal power plants made electricity expensive**
- **Maximum physical efficiencies are 60%(gas CCGT), coal 48% (supercritical), atomic (35%)**

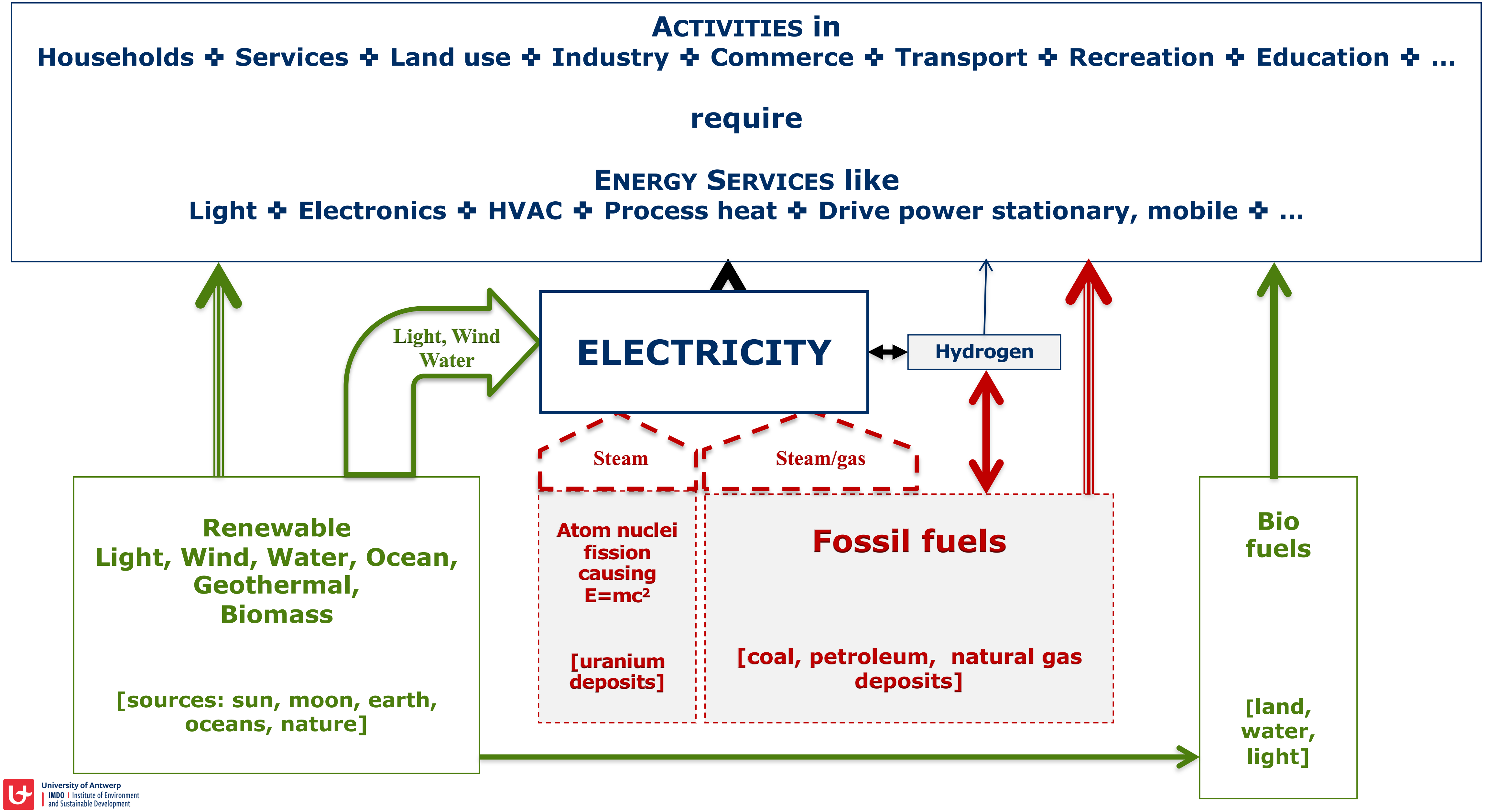
Electric power is a current at electronic speed, bridging continents within seconds

- **Electricity cannot be stored as such; it only can be uphold for very short time**
- **Storage requires transformation in chemical, mechanical energy, later re-transformed in power**
- **Transmission and distribution grids must fit the generation systems**

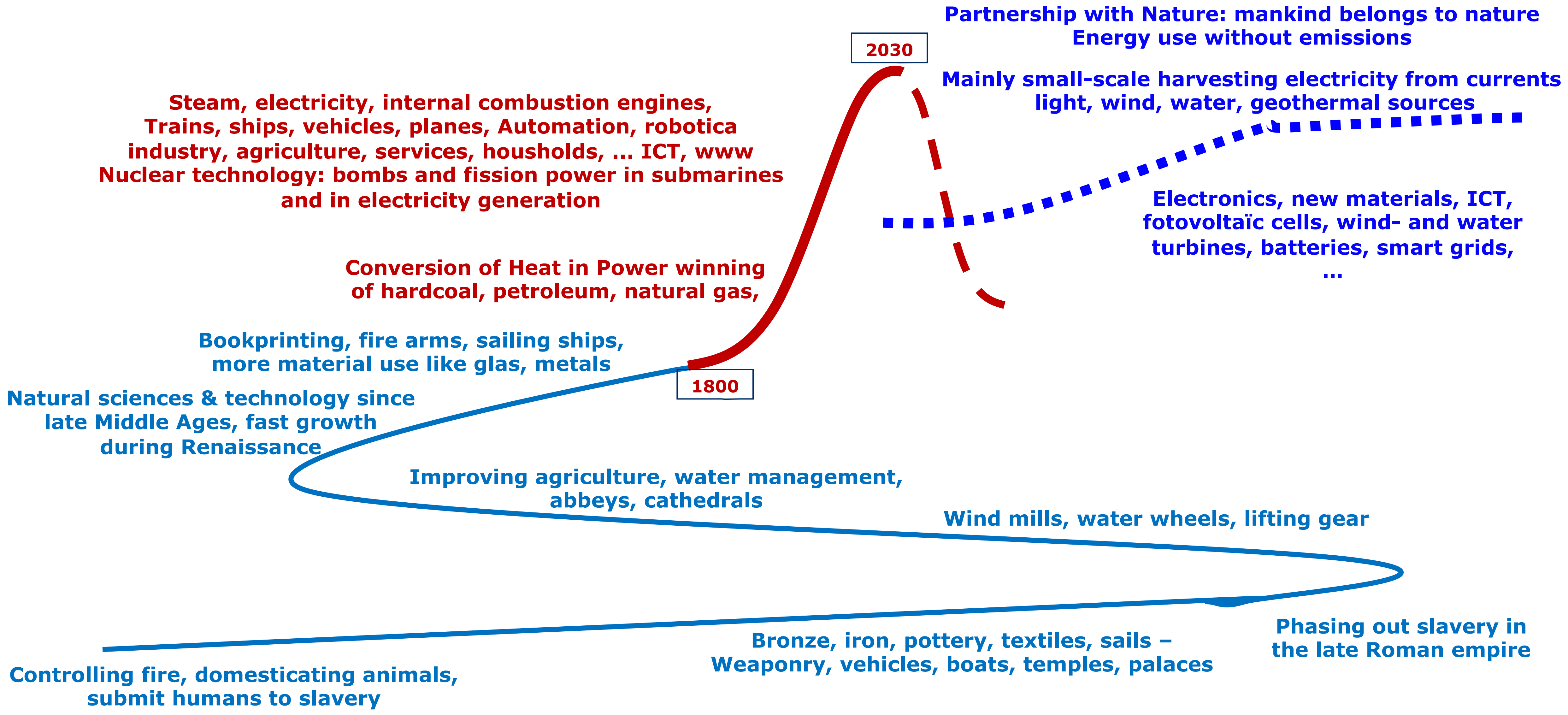
Electricity is rather a phenomenon than a commodity you can touch

- **Time, moments in time are crucial in handling and understanding electricity**
- **Electricity is best understood as power, expressed in Watt = Joule/second**
- **The aggregation of power over a time span is energy, like 1 kiloWatthour = 3.6 MegaJoules**

The central position of electricity in a modern energy economy



Three periods in the history of energy use (Europe as example)
1 [prehistory-1800] 2 [1800-2030] 3 [2000- ∞]

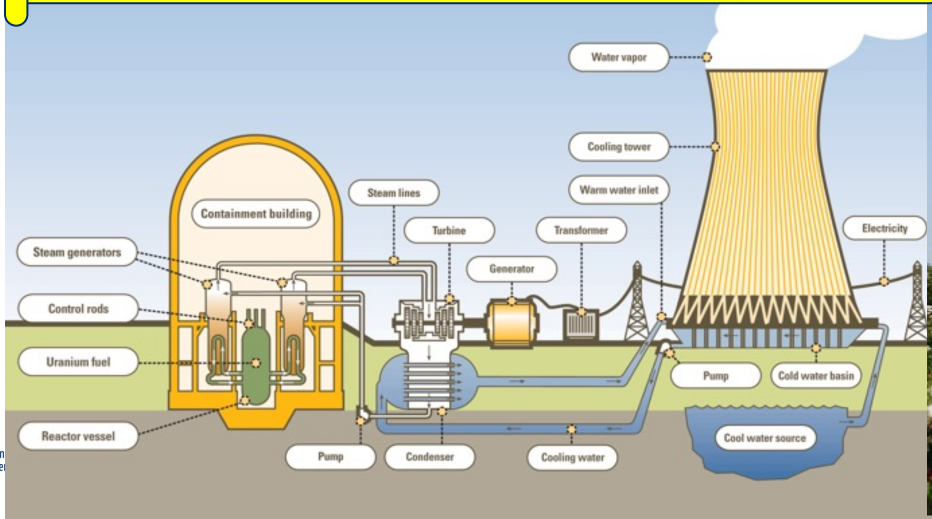


Technological reversals in electricity generation

18th – begin 21st century ⇔ 3rd millennium

Thermal flows, costly & risky ⇔ Harvesting ligth, wind, water

From cumbersome techniques on concentrated energy sources



To direct harvesting of diffuse, variable flows

Nanosciences bring
KEY NEW ENERGY TECHNOLOGIES

Photovoltaics

Power generation

- Direct generation of electricity from sunlight
- >20 times more efficient than photosynthesis
- Lowest electricity costs
- Decentralised generation
- Fluctuation with solar radiation

Power Electronics

Power transformation, transport and control

- Electricity converters
- Wind power to grid
- Digital control of electricity systems
- Efficient grids, HVDC, superconductors
- Digital frequency control → efficient e-motors

Batteries

Power storage

- High-density electro-chemical battery cells
- Flow batteries for longer-term-storage
- Strong density improve-ments and cost reduction
- Fuel cells
- Improved electrolysers

Electricity → Radiation

Material processing & Light

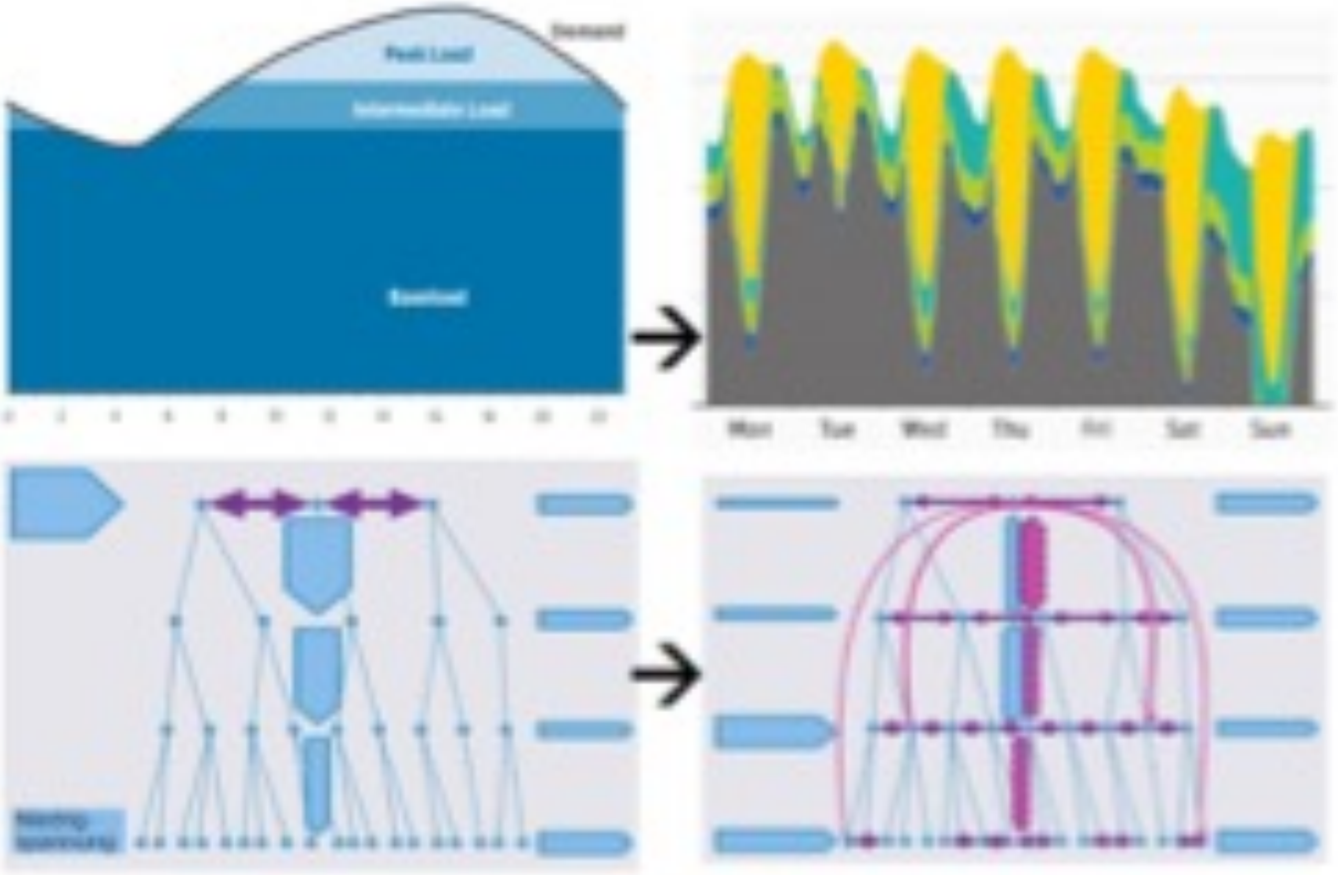
- LED, Laser, Microwave...
- 3D-printing: up to 75% material savings
- High life-cycle energy savings
- Efficient decentralised small series production

Very rapid performance boost and cost reduction well above macroscopic process learning curves: miniaturisation and speed/efficiency increase due to improved processes at nanoscale

Ruggero Schleicher-Tappeser
sustainable strategies

Flexibility sources allow full coverage with renewable electricity

Flexibility source	New technologies
Demand side management	power electronics, communication
Flexible generation	power electronics, materials
Energy storage	batteries, hydrogen conversion, power electronics
Sector coupling	power electronics, heat pumps, electric transport
Grids: Transmission & distribution	power electronics, digitalisation, superconductivity
Bottom-up system control logic	power electronics, local energy markets



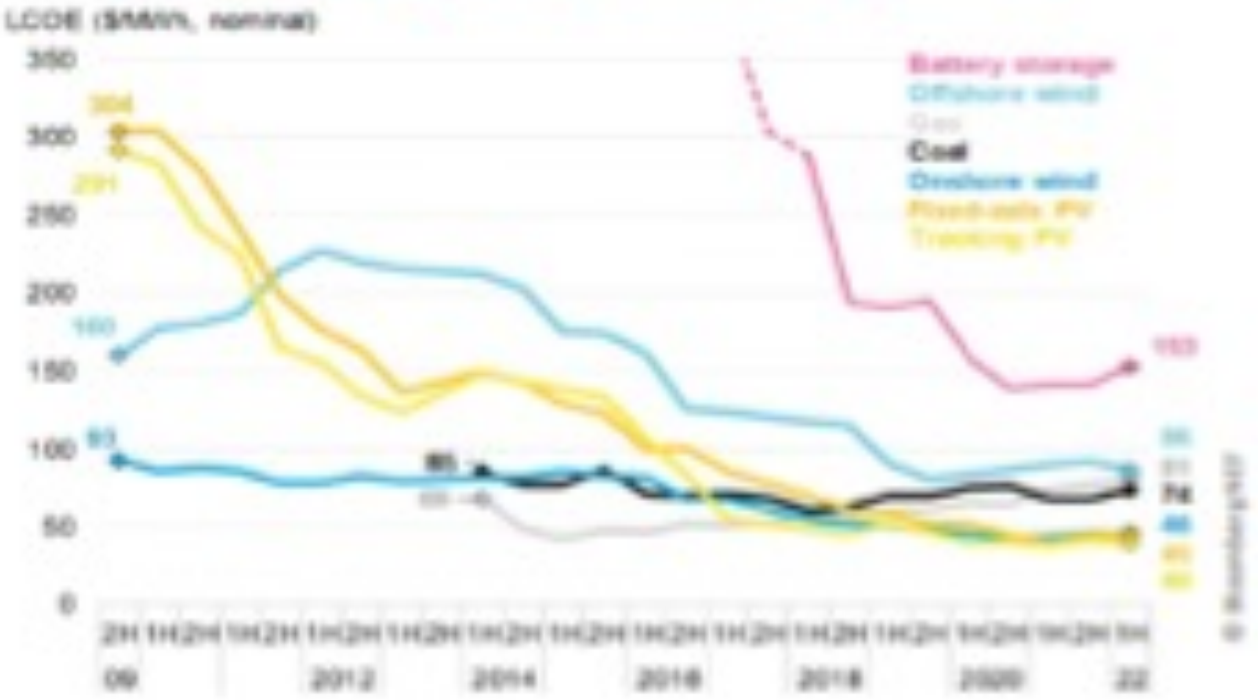
Calculations show: Combinations of these approaches can guarantee a fully renewable energy supply in Europe and the US at lower costs

Ruggero Schleicher-Tappeser
sustainable strategies

Photovoltaics are unbeatable due to nanoscience: Cost reduction stronger than in all other energy sources

1. **Extremely reliable.** No moving parts, no fuel, very low risks. Last for 30 to 40 years
2. **Mass production.** Classical economies of scale. New factories: 50 million modules per year
3. **Rapid innovation at nano-scale.** 2010-21: module efficiency 14%→ 22%
4. **Extremely scalable, up and down.** Energy transformation occurs at nano-level
5. **Rapid deployment.** Factories 2a, plants ½ a → 10 x shorter innovation cycles
6. **Strong potential for further cost reduction.** Perovskite cells , material reduction with BIPV

- No other energy source has matched efficiency gains, cost reductions and growth rates of PV
- **Nanotechnical innovation is the main driver for the extraordinary cost reductions – mass production experience comes only second**



PV and system change – strong resistance for 50 years

EXAMPLES

1973: Nixon's national energy research plan: no PV despite potential

1981: Reagan and U-turn of oil industry kill fledgling PV industry

2000: Introducing feed-in-tariffs: Success required parallel action to established structures

2009: Foundation process of IRENA: tedious

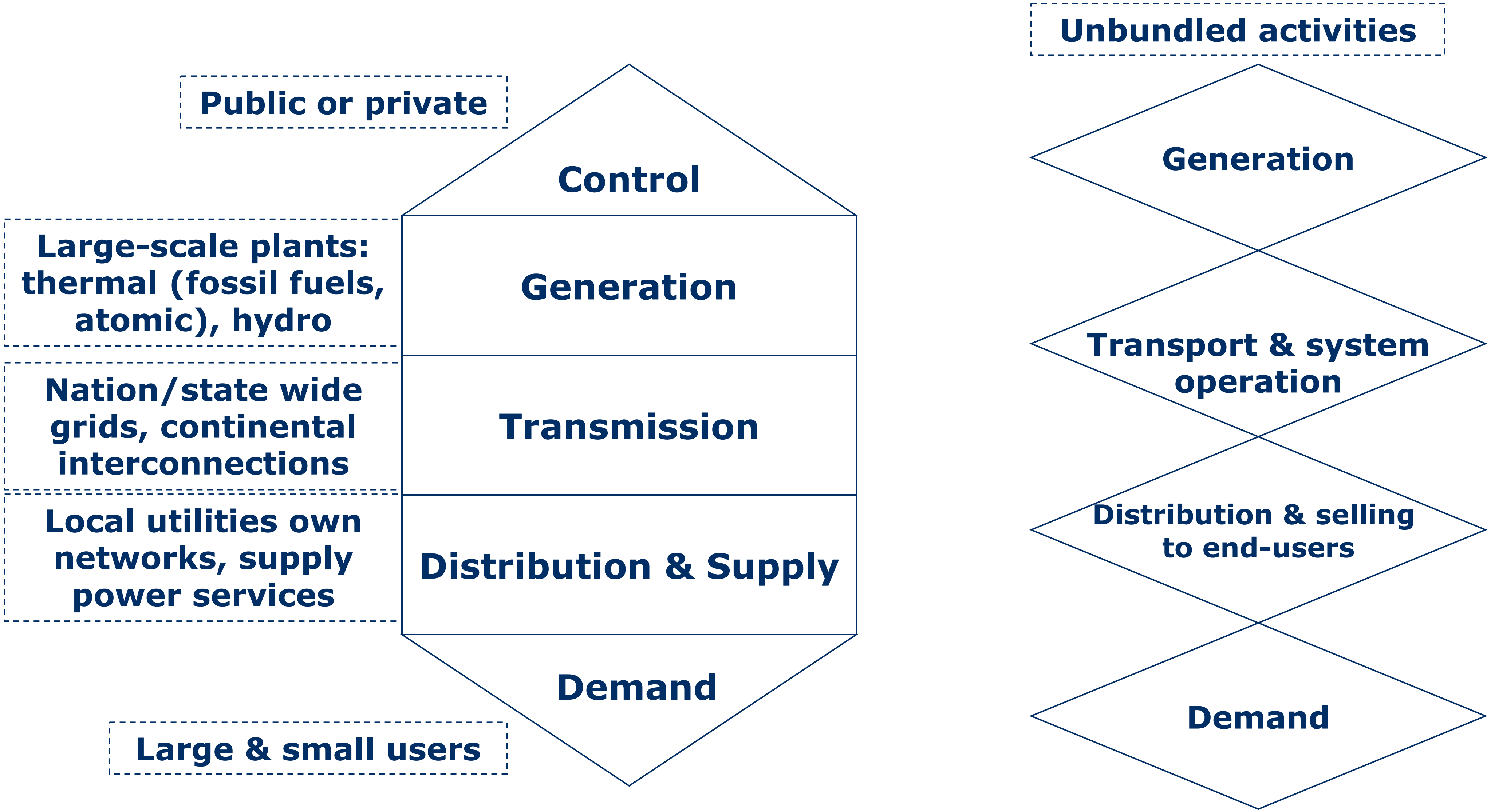
2011: European governments slash PV surge, 120'000 jobs lost in D

2014: No chance for large PV industry in Europe – French-German xGWp project fails

2008→China did not play by the big boys rules → 80% of global market, 34% of installations

2022: The hydrogen hype

From Vertical Integration to Unbundled systems



Cost economies of the main activities inform about best organisation forms

Economies of Electric Activity	Scale by unit SIZE or NUMBER of units	Scope over complementary activities	Density kWh/km^2 or kWh/km cable	suggest as the best form of ORGANISATION for the three activities
Generation	Yes	Combined Heat & Power	No	(Inter)national Electricity only/first Private/ competitive
Transmission	Yes	No	Yes	Interconnected Electricity only Franchised monopoly
Distribution	No	Yes	Yes	Local multi-product (electricity, gas, data) Public natural monopoly

Unbundling is a prerequisite for creating markets in electric power

Every electric power system needs Central Intelligence by an Independent System Operator (ISO)

- **Balances Supply ~ Demand at any moment**
  - **Ancillary services: balancing power (back-up, make-up), voltage and frequency control**
  - **Biddings to produce: day ahead, hour, quarter hour ahead adjustments**
  - **Measuring, billing, informing in real time**

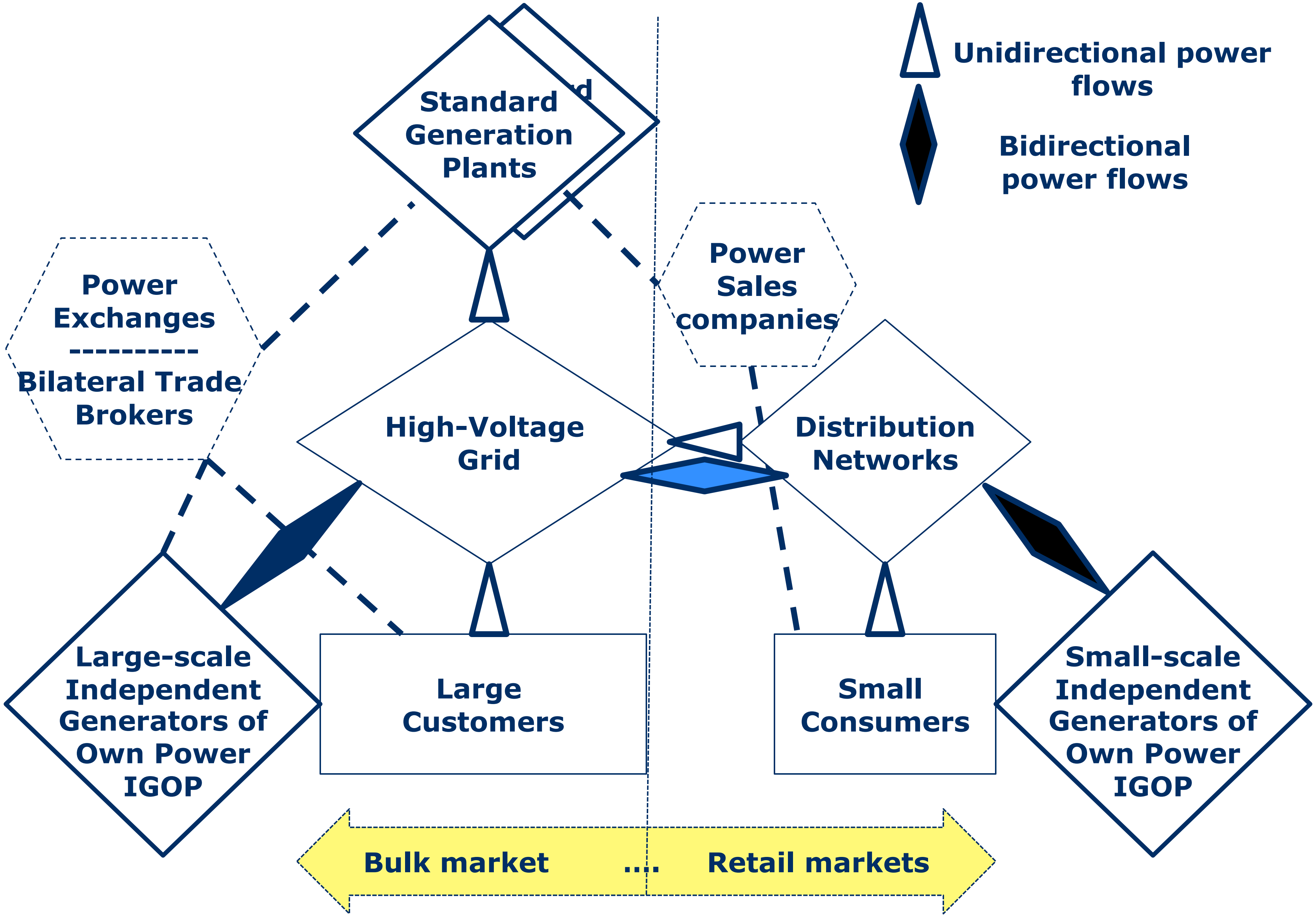
Grids = physical market places. For an economic competitive market is needed:

- **Reasonable numbers of suppliers & buyers**
- **Free entry & exit for power producers**
- **Harmonized, transparent, reciprocal conditions for all participants**

Bulk market = Transport grid & Retail markets = Distribution grids

- **Yes or no spliting network companies from suppliers, for competition among suppliers**
  - **For the bulk market YES**
  - **For retail markets ??? Here suppliers are only brokers, hence which transaction costs are added, which value is gained?**
  - **If no suppliers, franchised agents are responsible for service areas, what needs control by regulator, ombuds, complaint filings, etc.**
  - **The service area agent may be regulated as a promotor of energy efficiency and small-scale renewable elecrticity**
  - **Public utilities care for basic services to vulnerable customers**

Actors in changing electric power systems



Evaluation of the announced properties of ideal liberalised markets (matters to discuss)

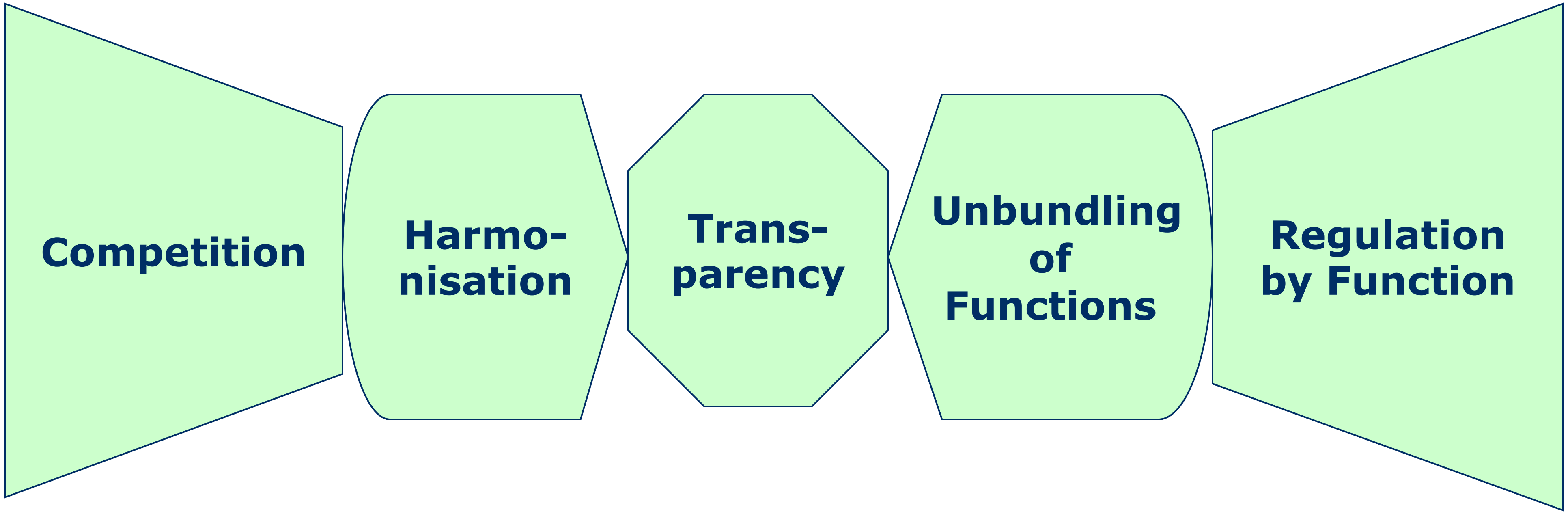
Criteria (properties to own; goals to attain)	Vertical Integration	Liberalised market
Sustainability: maximize energy efficiency & renewable electricity; avoid GHG emissions and nuclear liabilities	- Growth oriented - Nuclear Proliferation	+ new role Distribution utilities + decentral Generation + energy efficiency
Economic efficiency: minimize investment, operation, transaction, costs & maximize benefits; apply efficient pricing rules & allow various reliability levels; avoid bureaucratic slack (X-inefficiency)	+ central dispatch +/- large-scale units - overcapacities	+ Generators competition + grid coordination + Marginal Cost pricing
Regulatory efficiency: minimize information needs; self-enforcing incentives for ISO (broker fee system) and service area agents (include sustainability criteria)	- low transparency - mighty organisations - conflicting goals	+ higher transparency + consumer control on distribution + proper goals by activity
Institutional feasibility: embed electricity in overall energy policies	+ existent systems - against liberalisation	- new solutions + meets some policy goals
Equity: preclude monopoly profits; observe and respect diversity with appropriate services (avoid discriminations type I and type II)	? cross subsidies ? monopoly profits	+ open markets + no discrimination

Competition by Regulation

Competition requires strong Regulation

Diverging objectives by functions (activities)

Generation – Transport – Distribution



Electricity supply industry ⇔ Independent Generators of Own Power (IGOP) and End-users

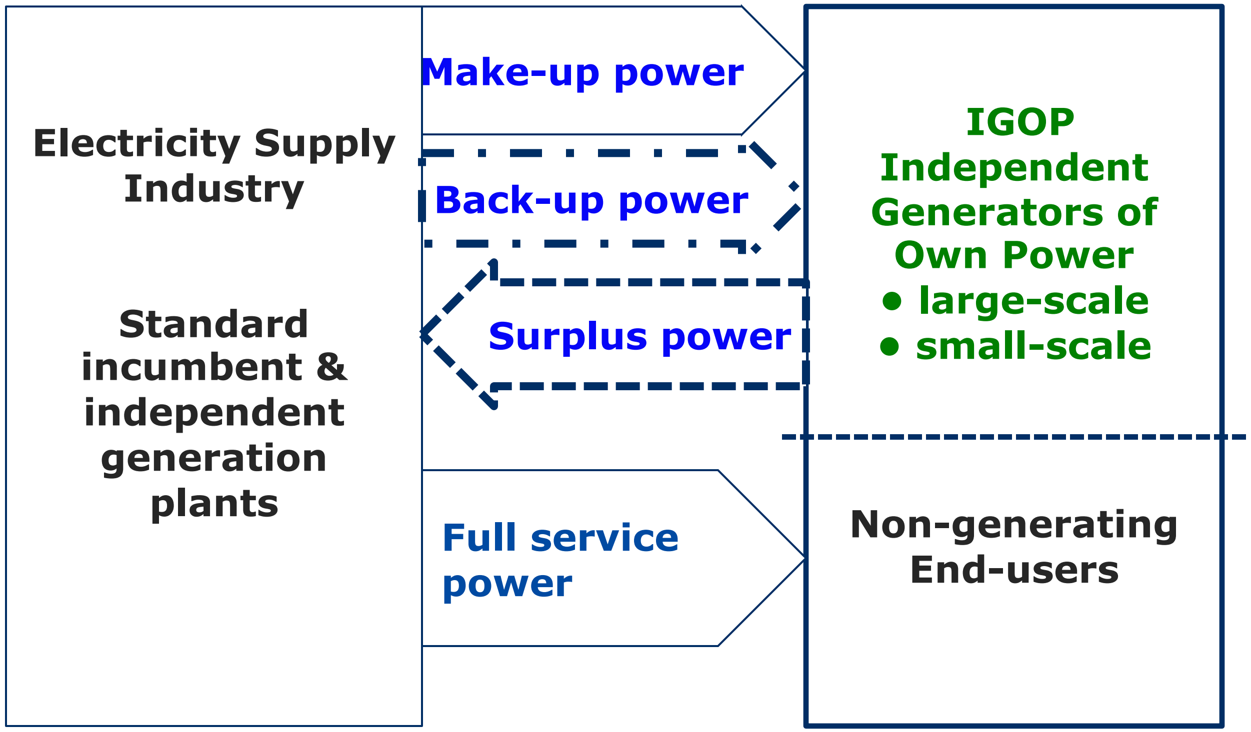
Two separate categories of generators:

a) Generators only selling electricity, mostly bulk power, and some ancillary services for system balance make-up, back-up (stand-by), quality services

b) Independent Generators of Own Power: once buying, once selling

= special economic status

> problematic "integration" in existing power systems



Electricity supply by IGOP is growing via small-scale renewable electricity (prosumers)

"Integrating" renewable electricity is an issue of "taking over"

Relation of IGOP to standard generation plant

Market price of a kWh supplied depends on	***Independent generator of own power (IGOP)***	***Standard generation plant***
Time of delivery (synchronous with system base to peak load fluctuations)	Delivery not at command, but net power offered according source supplies (renewable) and own demand for power or for heat (cogeneration)	Delivery at command when unit committed in advance; variable RE contribute when sources deliver on time of request
Speed of delivery (immediate, within seconds, minutes, hours)	Most IGOP capacity not available for dispatching.	Plants ready for dispatching but limited by ramping rates and flexibility; some plants specialized in flexibility
Place of delivery	Distributed locations near load centers, creating meshed deliveries	Central large-scale stations supply bulk of generation; renewable sources often distant from the grid
Reliability	Source, technology, project, environment, … specific	Source, technology, project, environment, … specific
Liability	Deliver power in surplus of own needs; IGOP switch roles producer-consumer	Produce power on demand – shunt power if not demanded

Electricity pricing varies with established power systems and rules

Important issue for large power consumers

E.g. Industrial plants chemistry, metallurgy, aluminum, …

- Electricity bill is a significant cost
- Possibility of generating own power (often with cogenerating heat)
- Individual bilateral contracts with power suppliers

Important issue for small power consumers

Electricity is indispensable for rich and poor households, for public services, SMEs, …

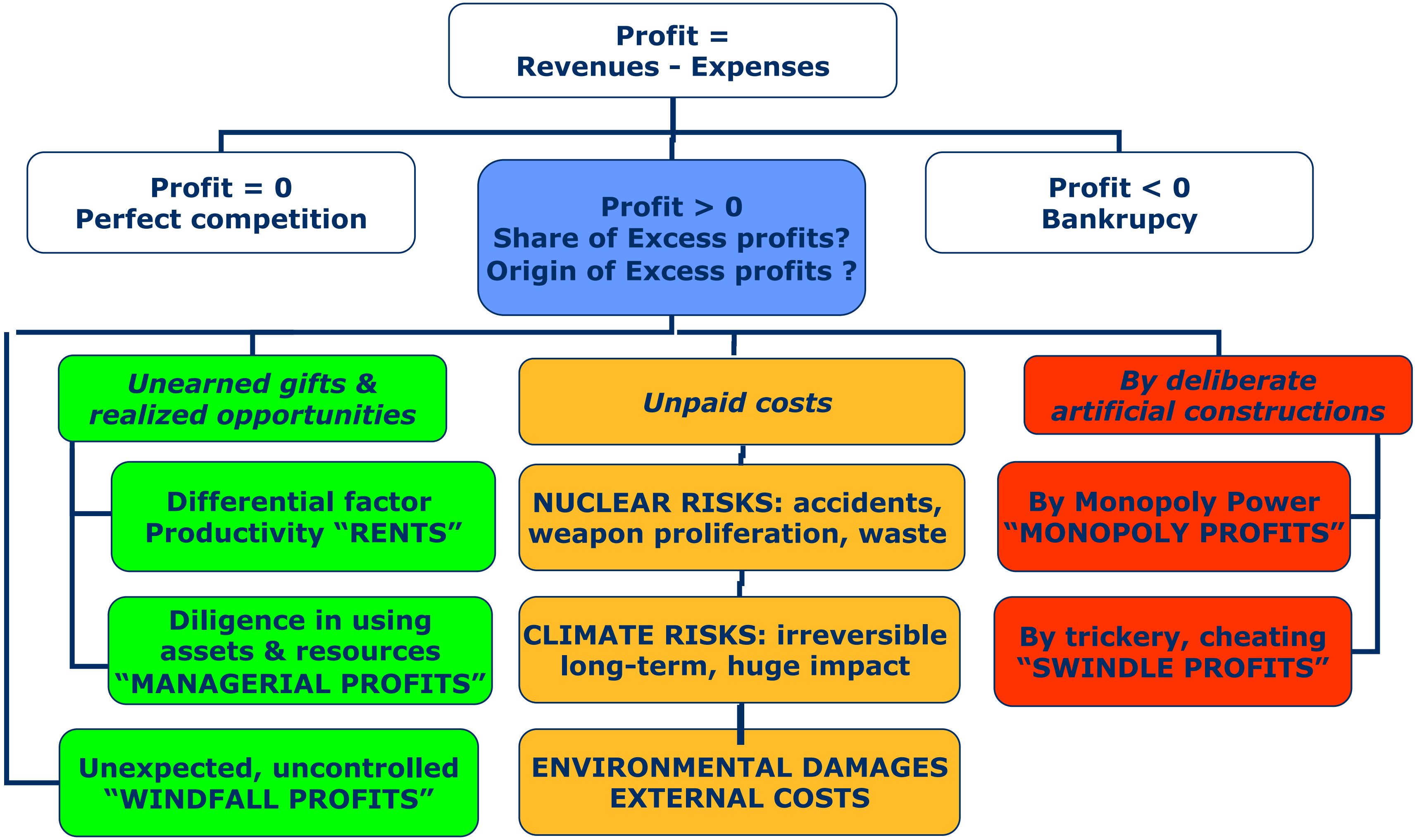
- For poor households, paying the monthly bill is often precarious
- Tariffs were regulated by commissions and generic by category
- In liberalised systems, suppliers create tariffs for the retail market
- Public regulators impose minimum service obligations for vulnerable households

Important issue for power suppliers

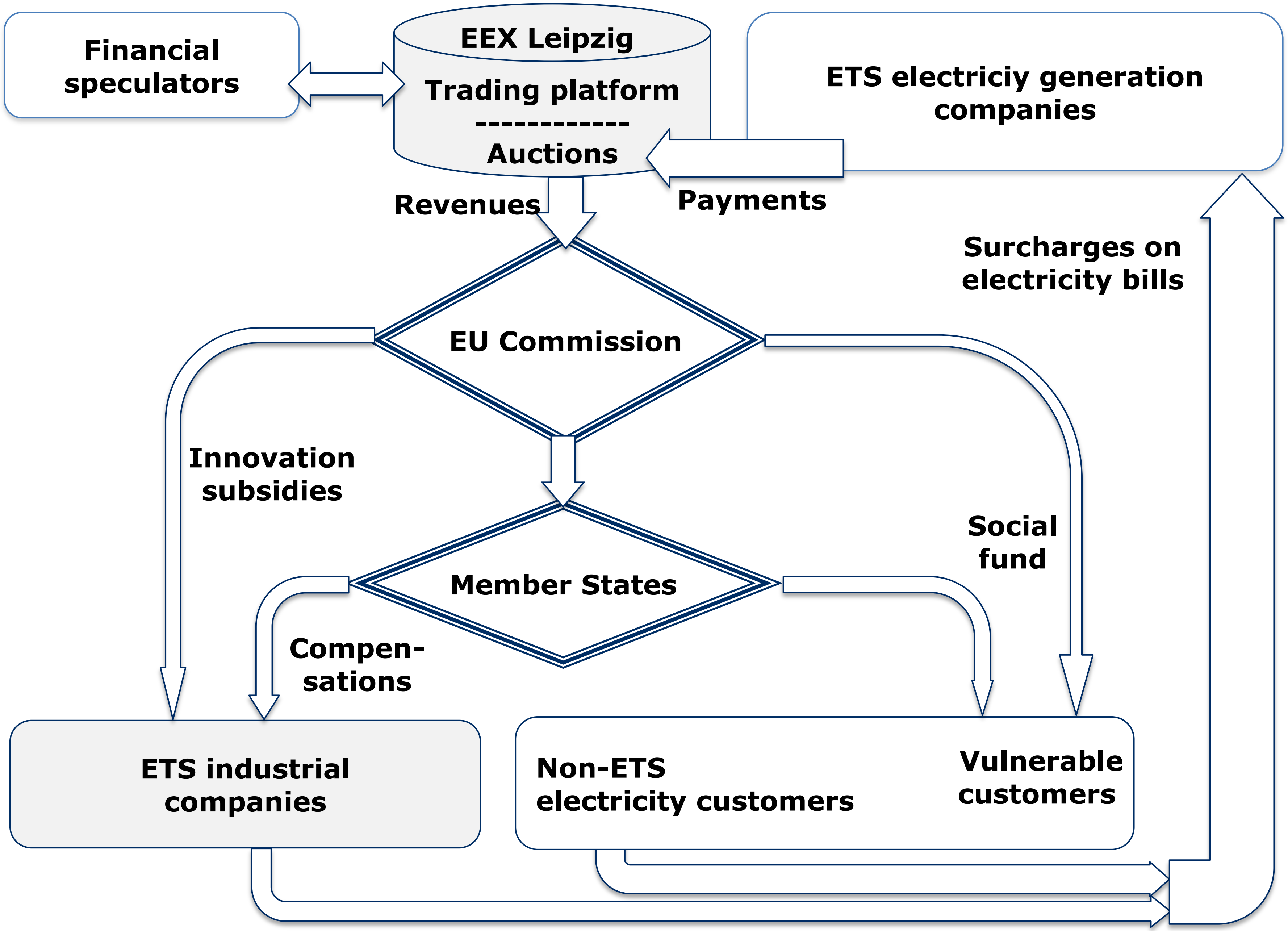
Profit = Revenues – Expenses = Price x Quantity sold – Cost of supply

- Monopoly / oligopoly power of giant electricity companies
- Small consumers, numerous and easy victims of monopolistic practices, "captive customers"
- Obstruction of the growth of IGOPs, prosumers

Taxonomy of (electricity sector) profits



Electric power oligopoly-monopoly companies and EU's climate policy flagship ETS



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Ending the obstruction to full & fast deployment of grassroot small-scale renewable power

- Sustainable carbon-free electricity systems are the *proper reference* for criteria (attributes to own; results to obtain) when evaluating power systems ⬄ using the existing systems as the reference
- By the *polluter pays principle* incumbent systems are liable for climate change and risks ⬄ holding the challengers (renewable electricity) responsible
- Develop and deploy *only* sustainable renewable electricity ⬄ energy 'Pantheon'

- Preference for secure and free local natural flows, harvested by prosumers, and *complemented* by centralized renewable plants ⬄ superseded by central power
- New electricity economics theory is needed: most capacities *not on command* but *zero fuel costs* ⬄ keeping the old theory
- Kickstart the transition, even existing assets may strand

- **Redirection of nuclear capability & assets**
  - Phased exit of nuclear power generation where it exists
  - Other task for IAEA: limited to security and safety (proliferation, waste management)
  - Refocusing and restructuring nuclear R&D for medical, industrial activities