

Conceptual Modeling to Explore Problem and Solution Space, Illustrated by Examples from Future Energy Systems

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Abstract

In the search for appropriate solutions, architects and stakeholders need ways to reason about concepts and their impact. The understanding, communication, and reasoning facilitates decision making. In this keynote, we explore conceptual models as the means to achieve all of these needs. We will make the abstract notion of conceptual models concrete by using future energy systems as an application area. Renewable energy systems have to help in solving the global sustainability development goals, especially the energy transition. The dynamics of both supply and demand of energy increases the complexity of the future energy systems.

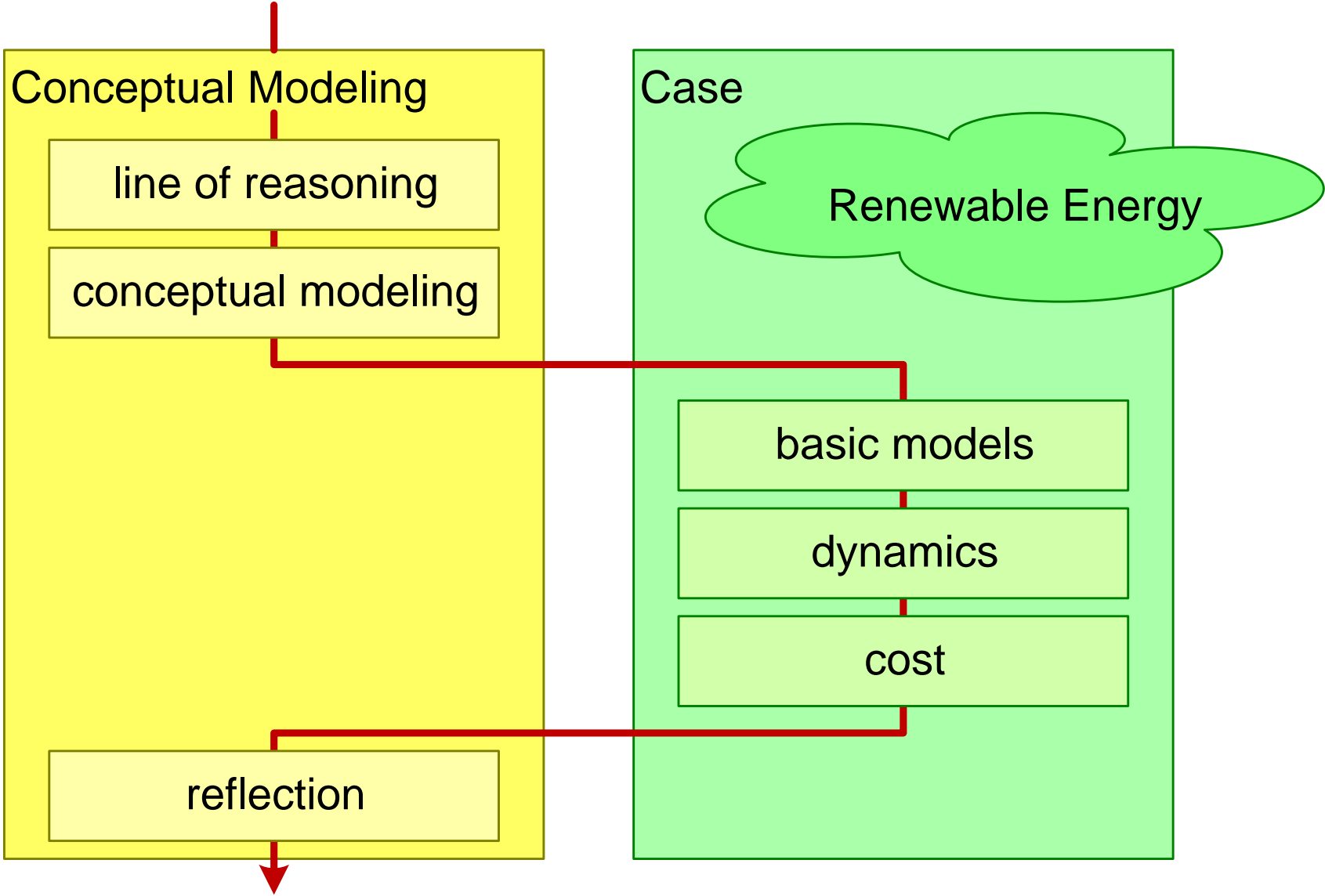
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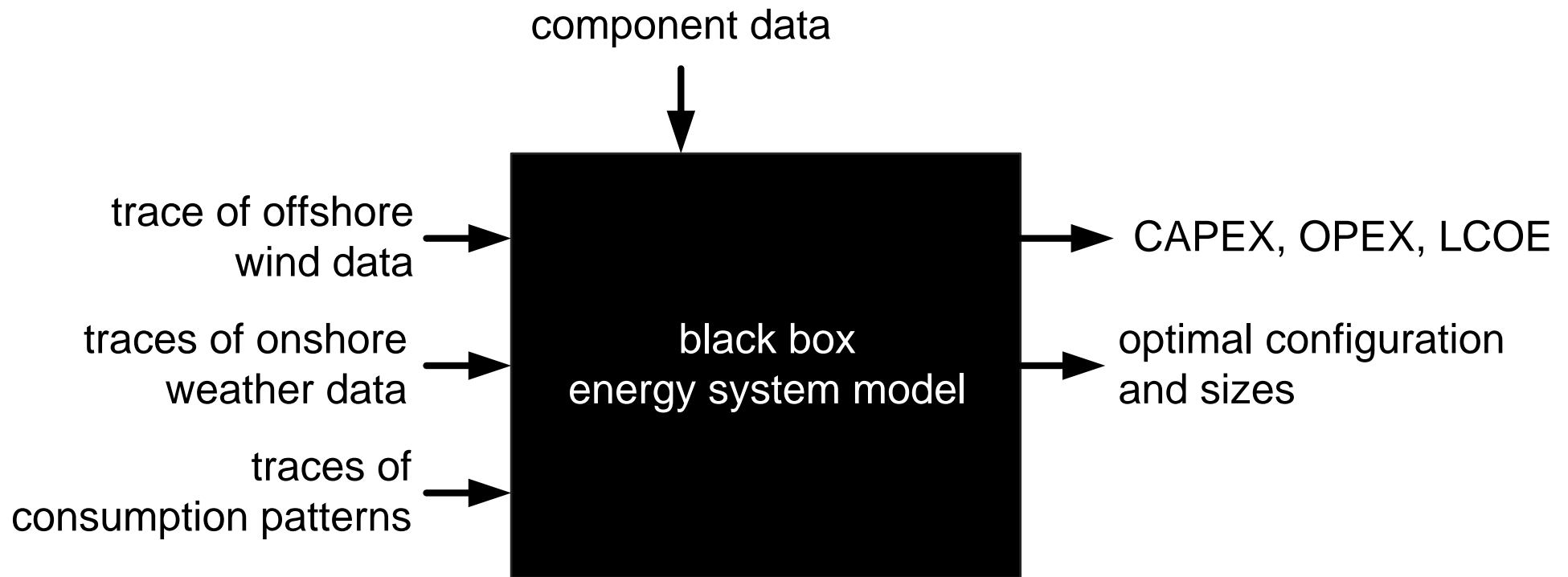
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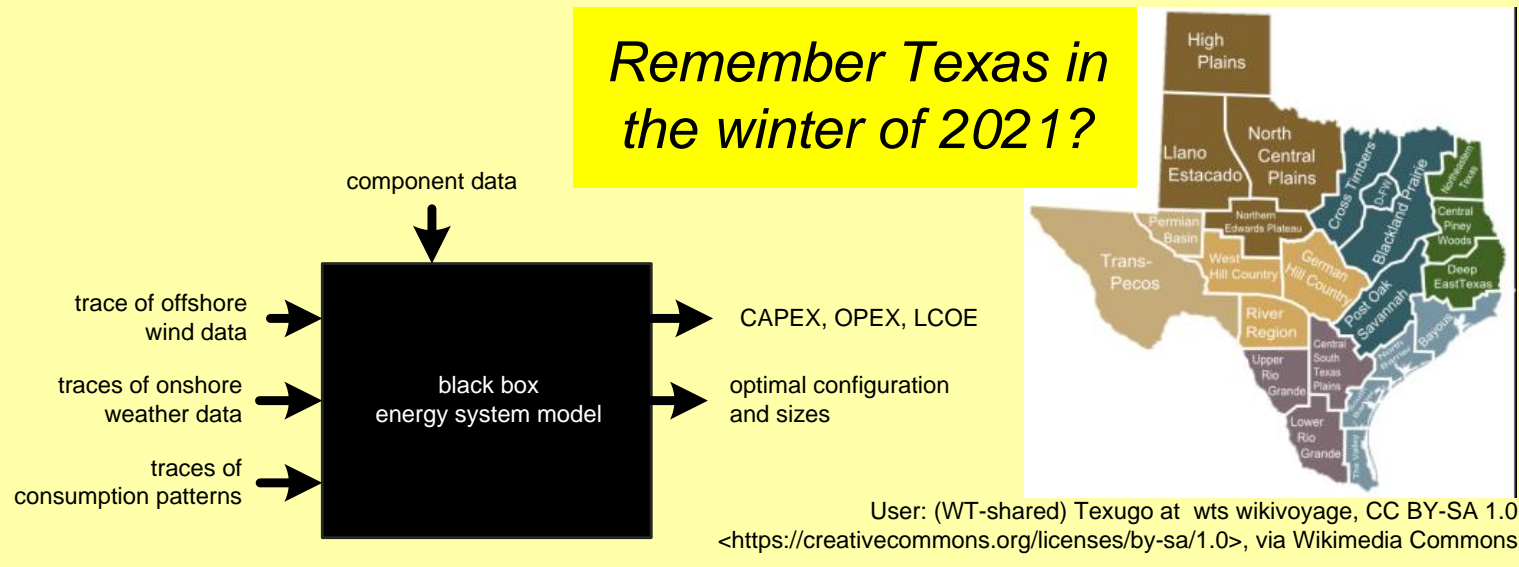
As-Is: System Model Calculates Optimum



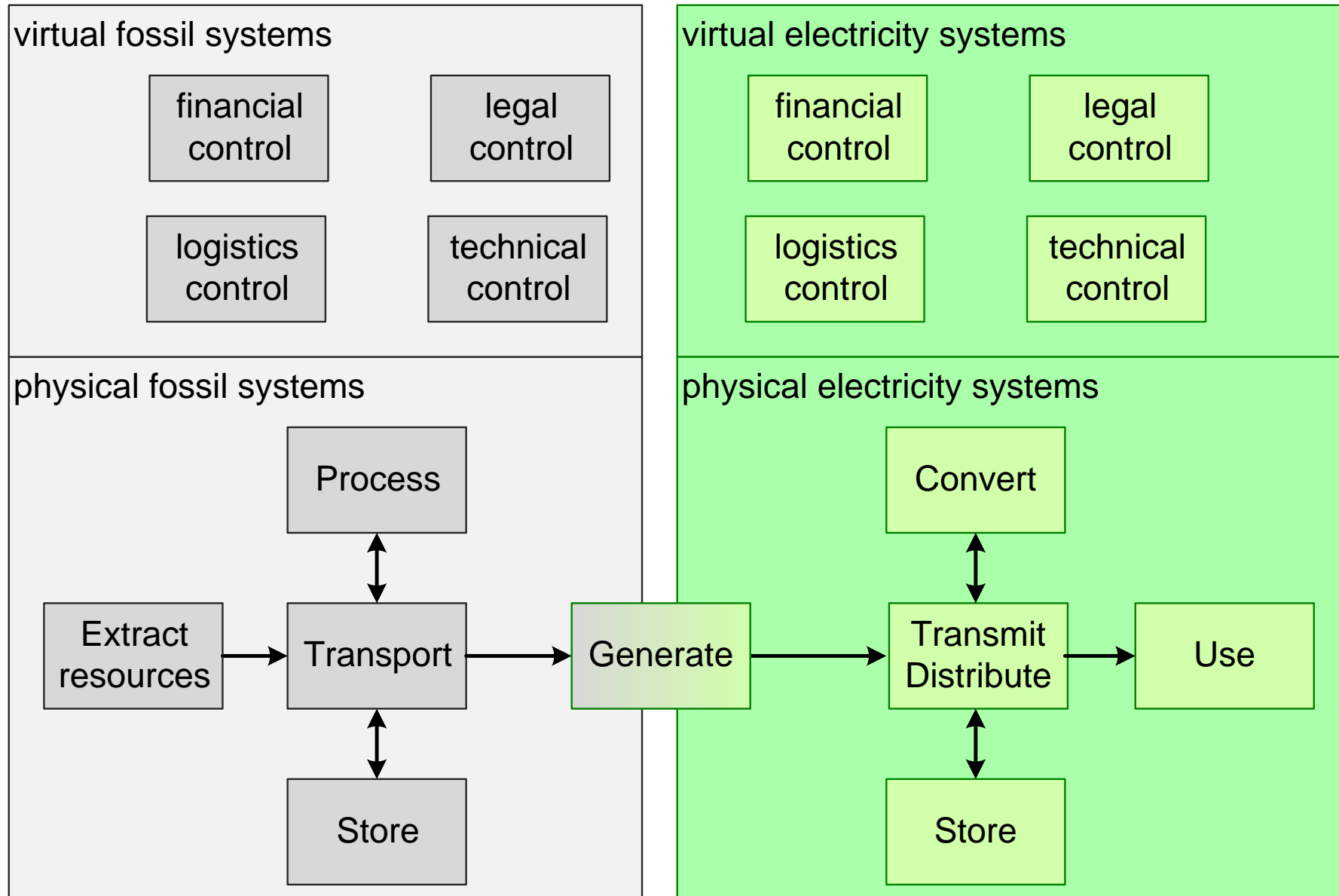
Problem: No Understanding, No Reasoning

Designers explore and find an **optimum**,
however, they **lack understanding**.

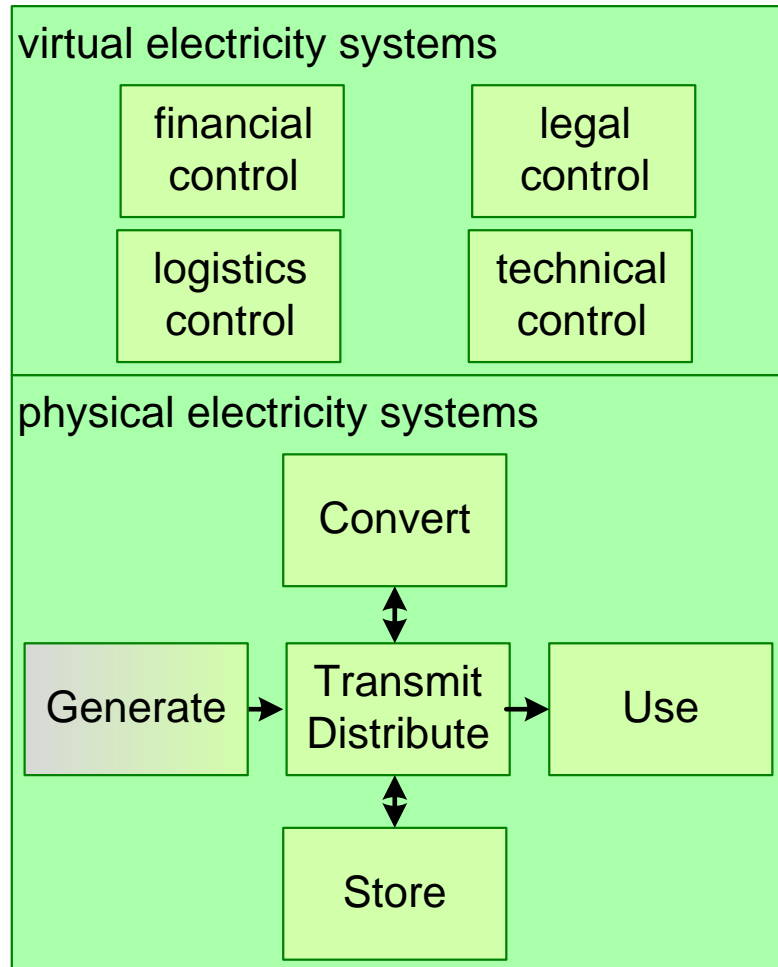
- How **sensitive** is the model for parameter or data **changes**?
- How do we reason about **use cases**?
- How do we reason about **options** and **risks**?
- What happens when we make **wrong assumptions**?



A Model of the As-Is Energy System



Main Questions about the Renewable Energy System



What is an **appropriate configuration** and **sizing** of **generation, transmission, distribution, storage, and demand control**

to obtain a **sustainable, robust, reliable, and affordable** energy system?

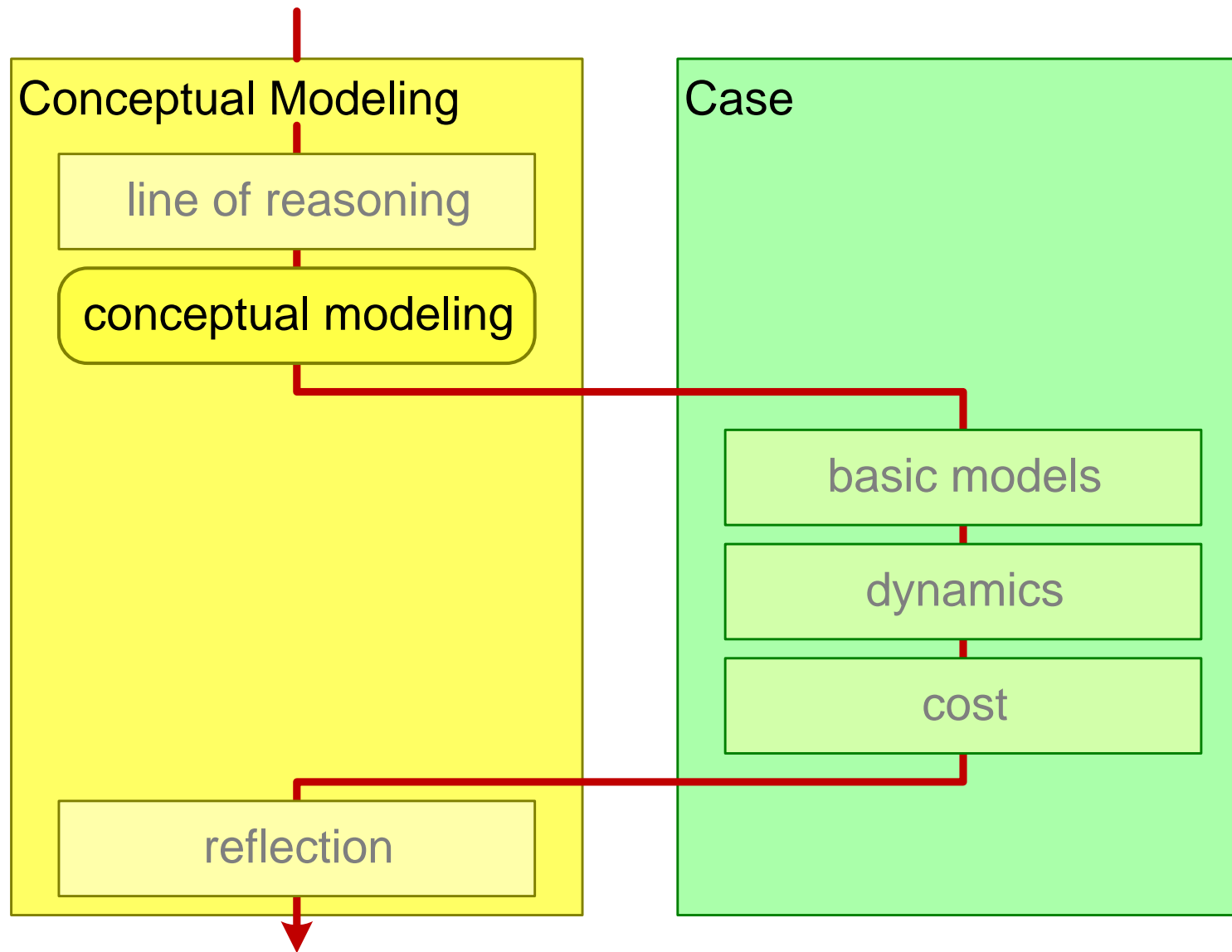
What **legal, financial, logistics, and technical control** strategies and measures

do we need to **operate** these **resources effectively**?

What Architecting Means do we need?

What **methods**, **techniques**, **formalisms**, **models**, and **tools** will help us to **create** and **explore problem** and **solution space** to **understand**, **communicate**, **reason**, and **facilitate decision making**, with **many diverse stakeholders** and a large set of **complicated technology options**, ranging from **idea** stage to fully **mature**, in a **complex natural environment**?

Conceptual Modeling



First Principle Models

First principle model: a model based on **theoretical** principles.

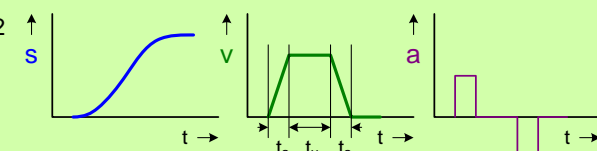
A first principle model **explains** the desired property from first principles from the **laws of physics**.

A first principle model **requires values** for **incoming parameters** to calculate results.

first principle model $t_{\text{top floor}}$ elevator

$$v = \frac{dS}{dt} \quad a = \frac{dv}{dt} \quad j = \frac{da}{dt}$$

Position in case of uniform acceleration:

$$S_t = S_0 + v_0 t + \frac{1}{2} a_0 t^2$$


$t_{\text{top floor}} = t_a + t_v + t_a$

$$t_a = v_{\text{max}} / a_{\text{max}}$$

$$S(t_a) = \frac{1}{2} * a_{\text{max}} * t_a^2$$

$$S_{\text{linear}} = S_{\text{top floor}} - 2 * S(t_a)$$

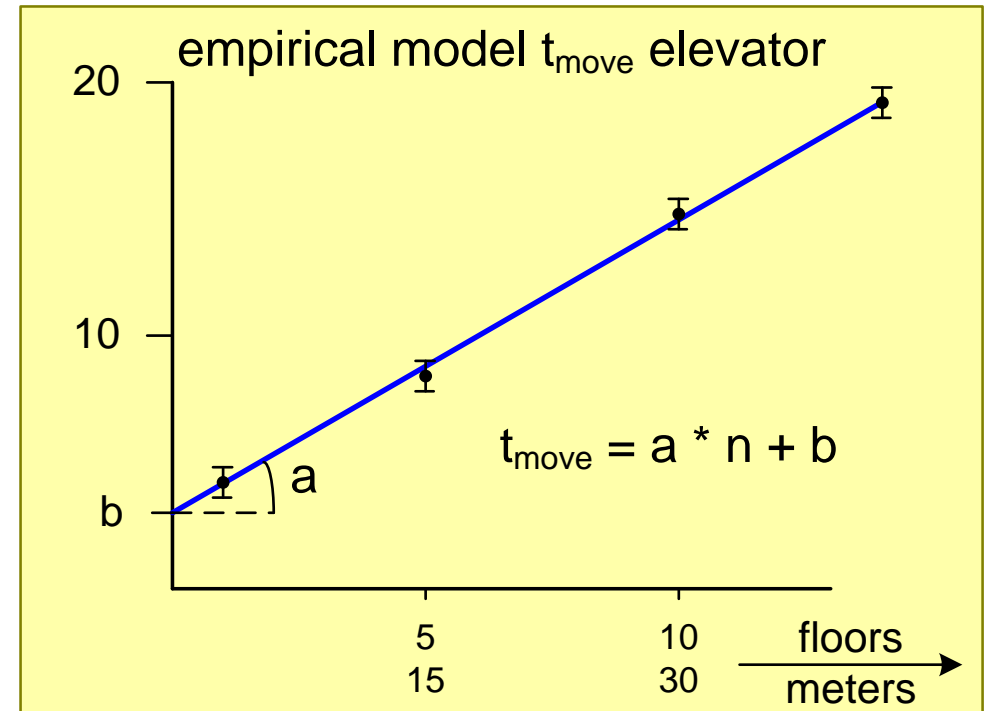
$$t_v = S_{\text{linear}} / v_{\text{max}}$$

Empirical Models

Empirical model: a model based on **observations** and **measurements**.

An empirical model **describes** the observations.

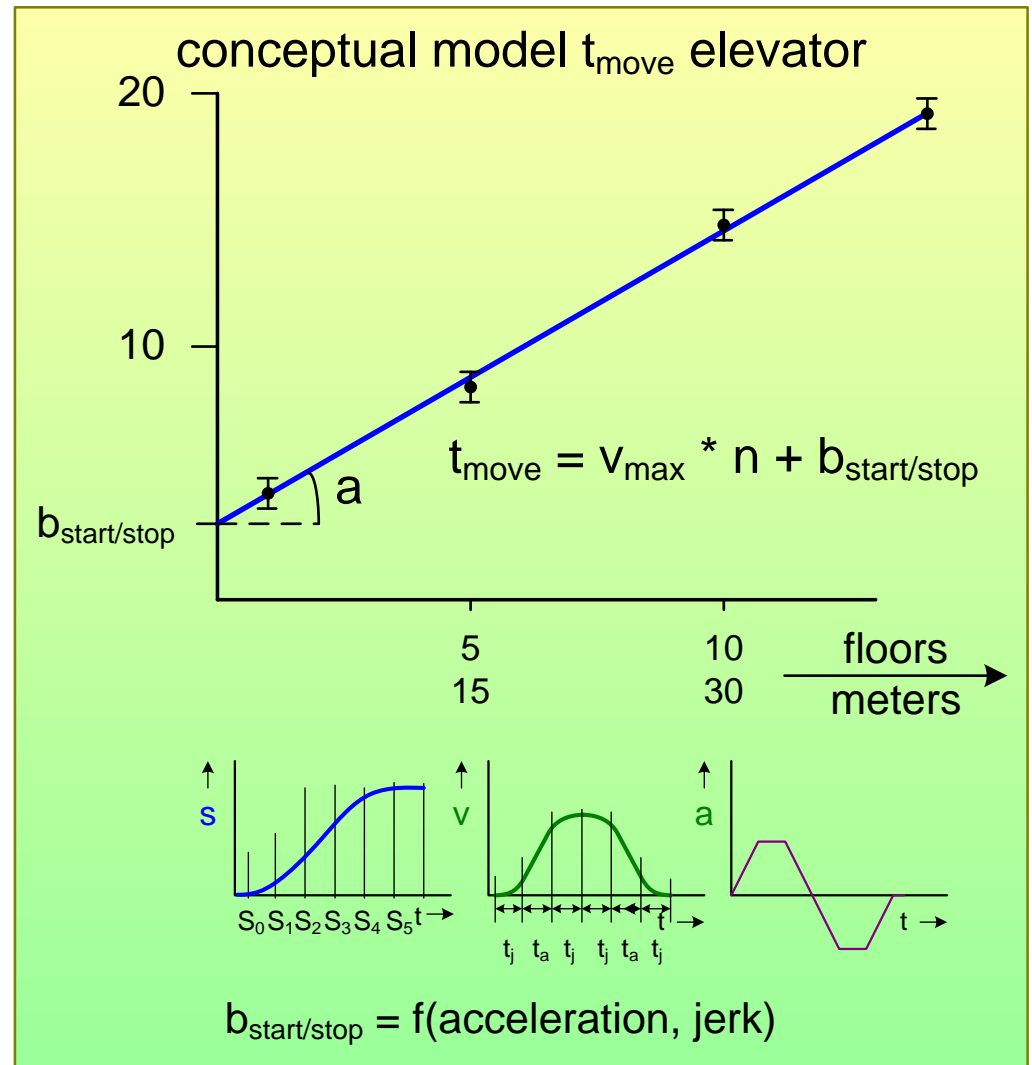
An empirical model provides **no understanding**.



Conceptual Models

Conceptual model: a model **explaining observations** and **measurements** using a selection of **first principles**.

A conceptual model is a **hybrid** of empirical and first principle models; **simple** enough to **understand** and to **reason, realistic** enough to make **sense**.

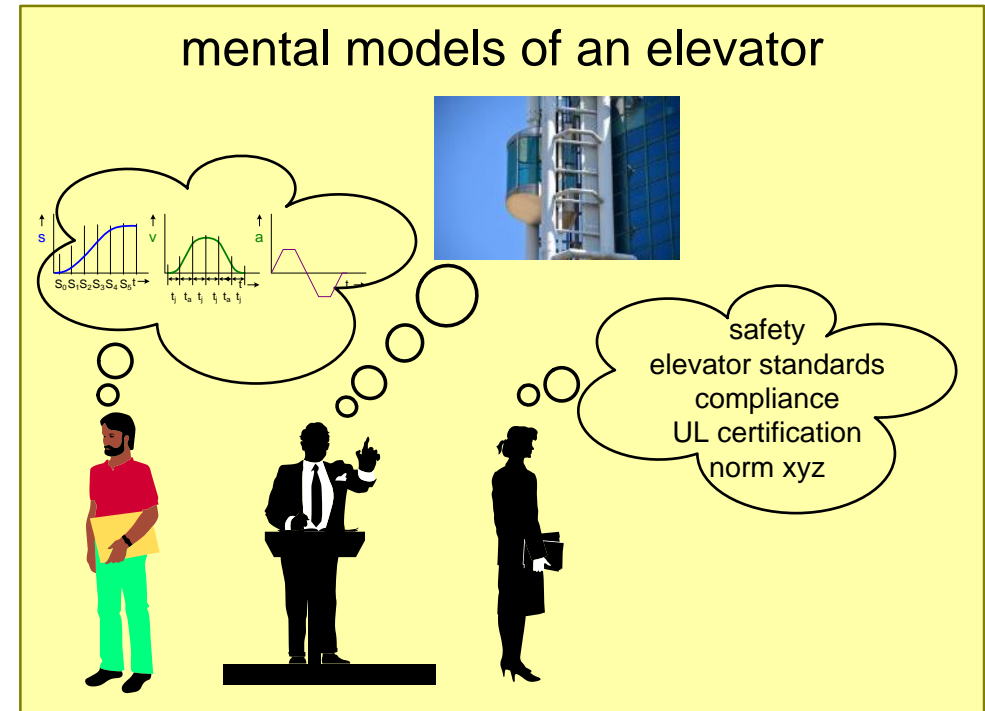


Mental Models

Mental Models are models in our **human brains**. These models depend entirely on the **individual** and his/her background

Mental models help us to **think**.

Individuals may have a **verbal** or **visual** orientation, they may think in **concrete** or **abstract** ways, etc.



Simulations

Simulation: an executable model based on **first principle** and **empirical models**.

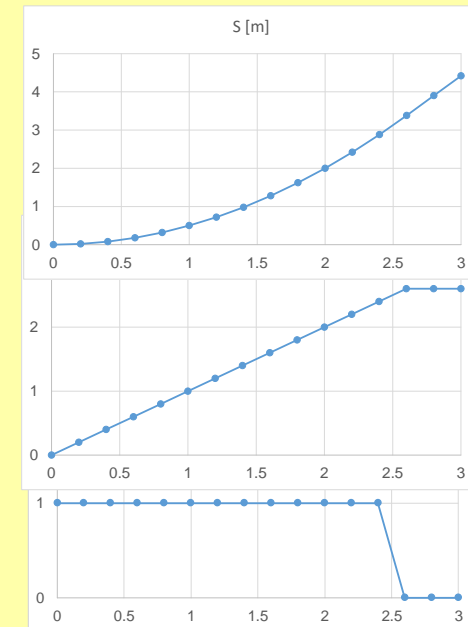
Designers run simulations to **explore**, **analyze**, and **gain insights**.

A simulation provides **understanding**, when **the users transform** the outcomes into **insights**.

simulation of an elevator

dt	0.2 s
vmax	2.5 m/s
amax	1 m/s ²

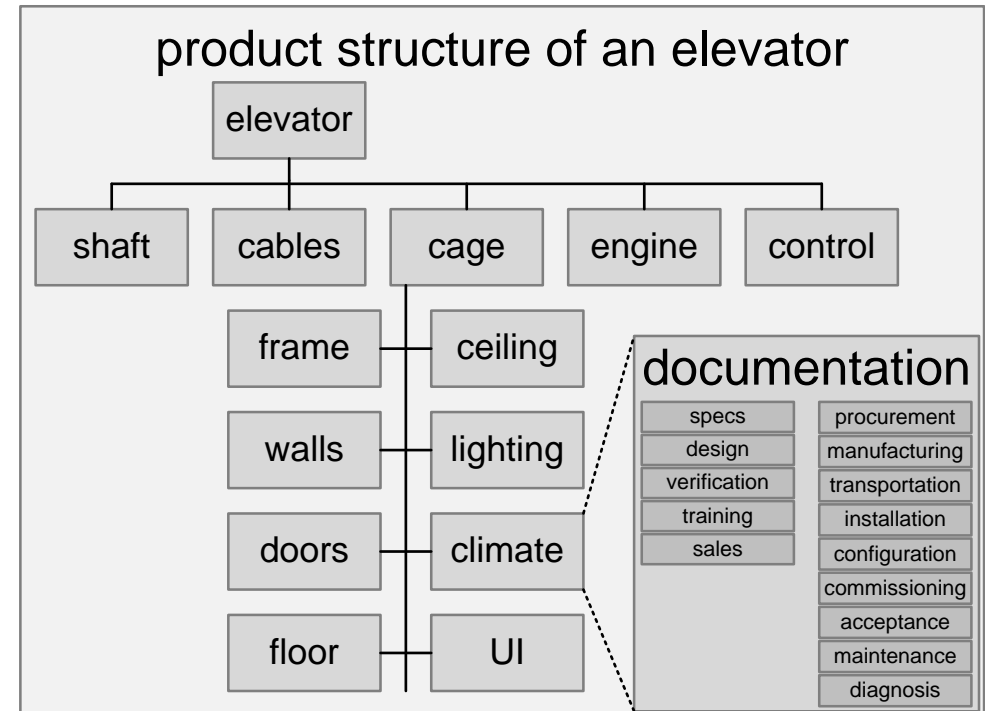
t (s)	s (m)	v (m/s)	a (m/s ²)
0	0	0	1
0.2	0.02	0.2	1
0.4	0.08	0.4	1
0.6	0.18	0.6	1
0.8	0.32	0.8	1
1	0.50	1	1
1.2	0.72	1.2	1
1.4	0.98	1.4	1
1.6	1.28	1.6	1
1.8	1.62	1.8	1
2	2.00	2	1
2.2	2.42	2.2	1
2.4	2.88	2.4	1
2.6	3.38	2.6	0
2.8	3.90	2.6	0
3	4.42	2.6	0
3.2	4.94	2.6	0
3.4	5.46	2.6	0



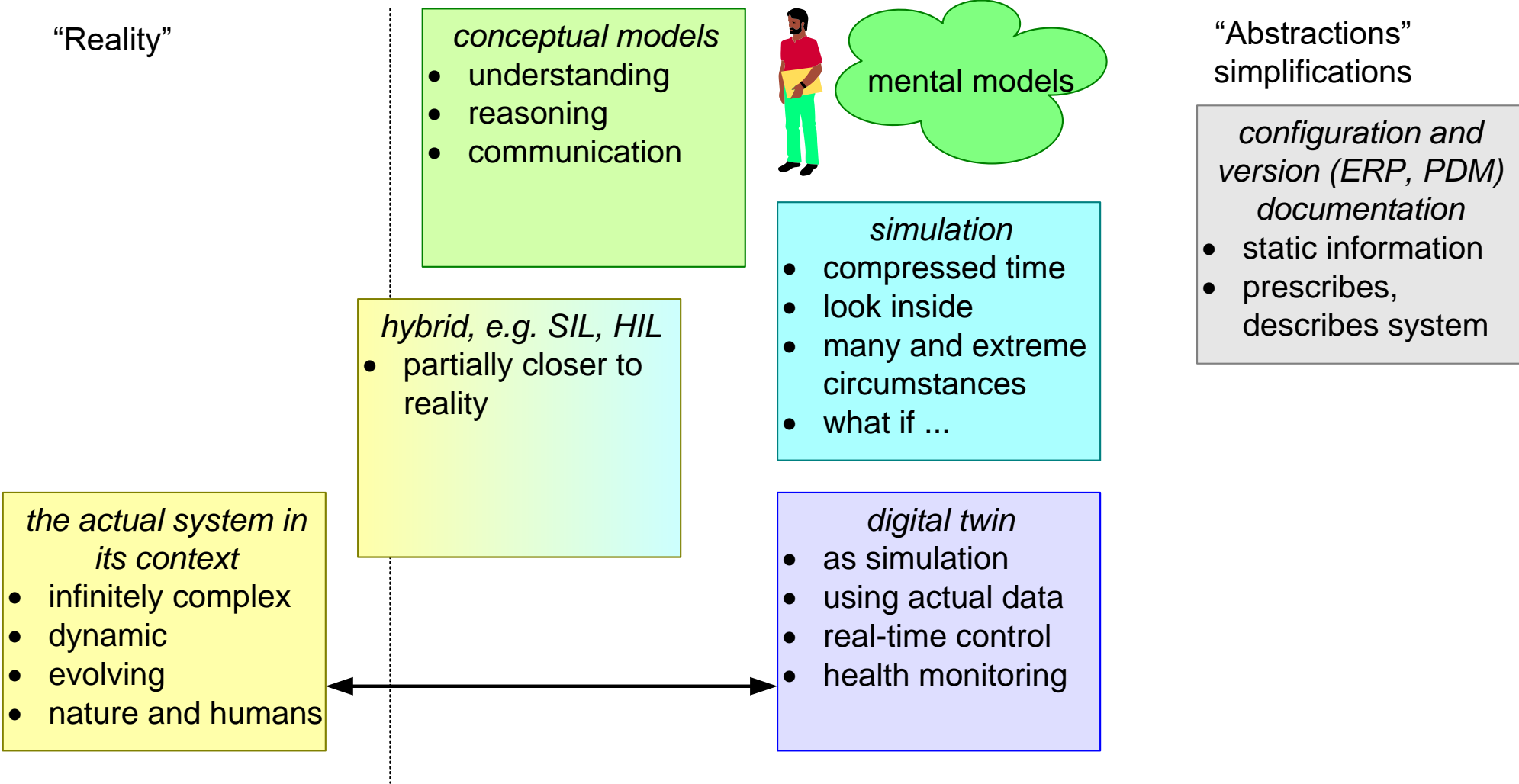
Product Structure and Documentation

The **Product Structure** prescribes the **parts hierarchy**. Each part in the hierarchy has associated **documentation** and **information** for the entire **life cycle**.

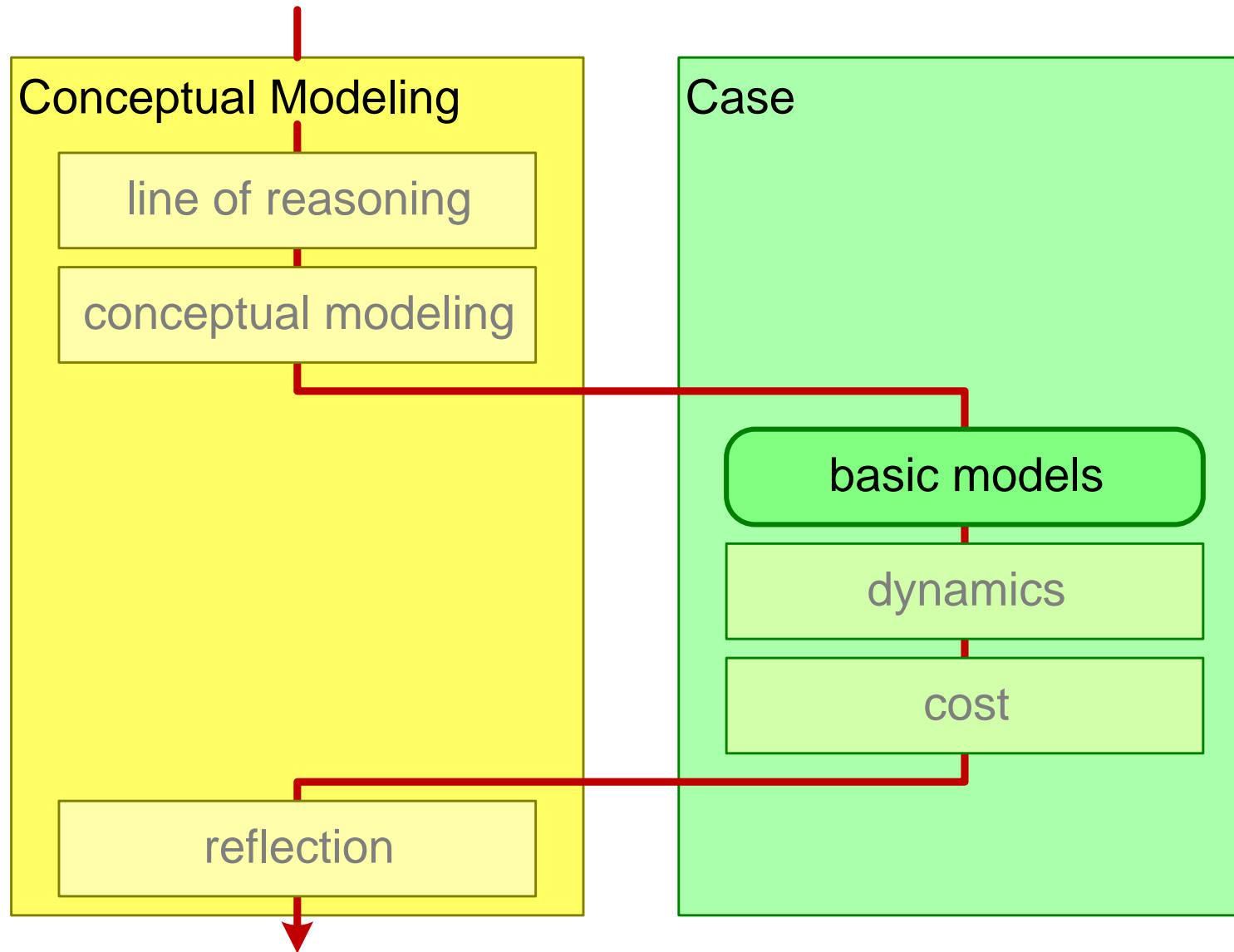
The Product Structure and associated documentation help the organization to **manage** all processes from creation to decommissioning and recycling, via **ERP, PDM, PLM** etc. systems.



Map of Various Model Types



Case



Starting Point: Irish Energy Data

NI: Northern Ireland IE: Ireland		GMT Offset	NI Generation	NI Demand	NI Wind Availability	NI Wind Generation	NI Solar Availability	NI Solar Generation	IE Generation	IE Demand	IE Wind Availability	IE Wind Generation	SNSP
01-01-2020 00:00	0	805.808	736.418	268.222	267.818	0	0	2708.45	3035.95	331.08	324.1	21.3%	
01-01-2020 00:15	0	808.93	727.636	271.798	272.509	0	0	2757.59	3001.06	332.35	324.88	19.8%	
01-01-2020 00:30	0	799.635	715.448	264.655	264.816	0	0	2765.93	2956.65	326.64	318.97	19.2%	
01-01-2020 00:45	0	781.243	704.161	256.279	255.498	0	0	2741.16	2912.98	319	311.37	18.7%	
01-01-2020 01:00	0	828.025	714.902	256.845	257.602	0	0	2741.16	2912.98	319	311.37	18.7%	
01-01-2020 01:15	0	852.065	708.819	265.536	265.553	0	0	2741.16	2912.98	319	311.37	18.7%	
01-01-2020 01:30	0	802.759	693.102	269.476	269.548	0	0	2741.16	2912.98	319	311.37	18.7%	
01-01-2020 01:45	0	813.181	680.919	289.076	287.469	0	0	2741.16	2912.98	319	311.37	18.7%	
01-01-2020 02:00	0	829.529	669.815	307.113	305.538	0	0	2741.16	2912.98	319	311.37	18.7%	
01-01-2020 02:15	0	838.336	655.935	325.403	324.447	0	0	2741.16	2912.98	319	311.37	18.7%	
01-01-2020 02:30	0	845.129	640.637	336.459	334.505	0	0	2741.16	2912.98	319	311.37	18.7%	
01-01-2020 02:45	0	852.376	624.397	342.903	339.328	0	0	2741.16	2912.98	319	311.37	18.7%	
01-01-2020 03:00	0	880.49	615.8	366.08	362.413	0	0	2741.16	2912.98	319	311.37	18.7%	
01-01-2020 03:15	0	840.47	605.929	364.687	299.381	0	0	2741.16	2912.98	319	311.37	18.7%	



Michael 1952, CC BY-SA 4.0 <<https://creativecommons.org/licenses/by-sa/4.0/>> via Wikimedia Commons

<https://www.eirgridgroup.com/how-the-grid-works/renewables/>

Simulation Using Hydrogen Storage

wind trace data		
year	day	production
2018	1	44214
2018	2	39969
2018	3	51687
2018	4	19293
2018	5	15842
2018	6	26849
2018	7	14014
2018	8	43098
2018	9	50887

use
- daily use
21370

surplus
22844
18599
30317
-2077
-5528
5479
-7356
21729
29517

convert
* η_{H_2}
50%

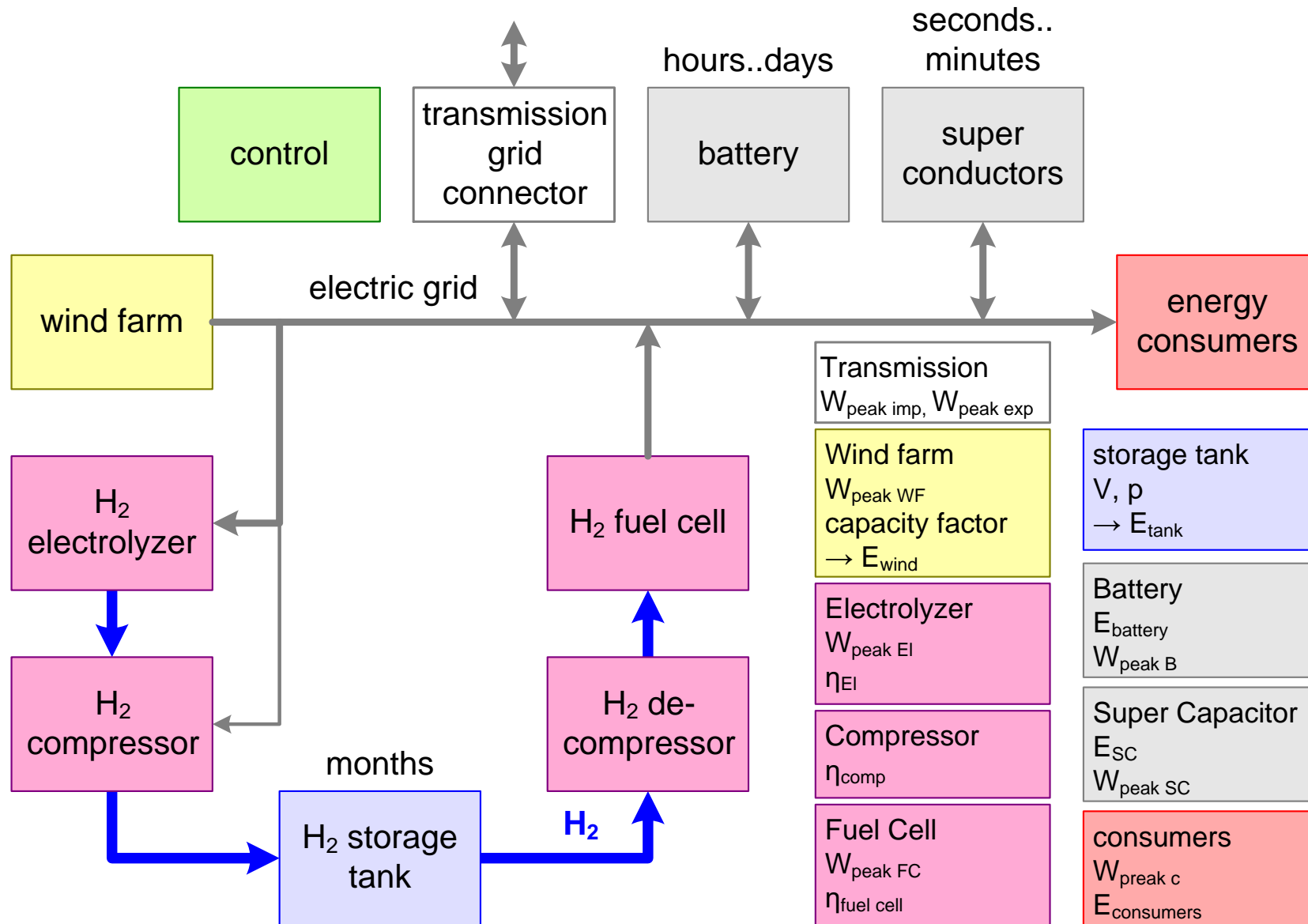
store/retrieve	
delta	storage
11422	700000
9300	709300
15159	724458
-2077	722382
-5528	716854
2740	719593
-7356	712237
10864	723101
14759	737860

aggregated production		
	2017	2018
jan	1179179	842549
feb	849591	1221703
mar	881203	1134683
apr	653040	863695
may	571785	503499
jun	322225	544853
jul	351038	522236
aug	618113	746528
sep	832528	710308
oct	968051	946287
nov	1270278	710351
dec	1041645	1100137
unscaled	9538677	9846828

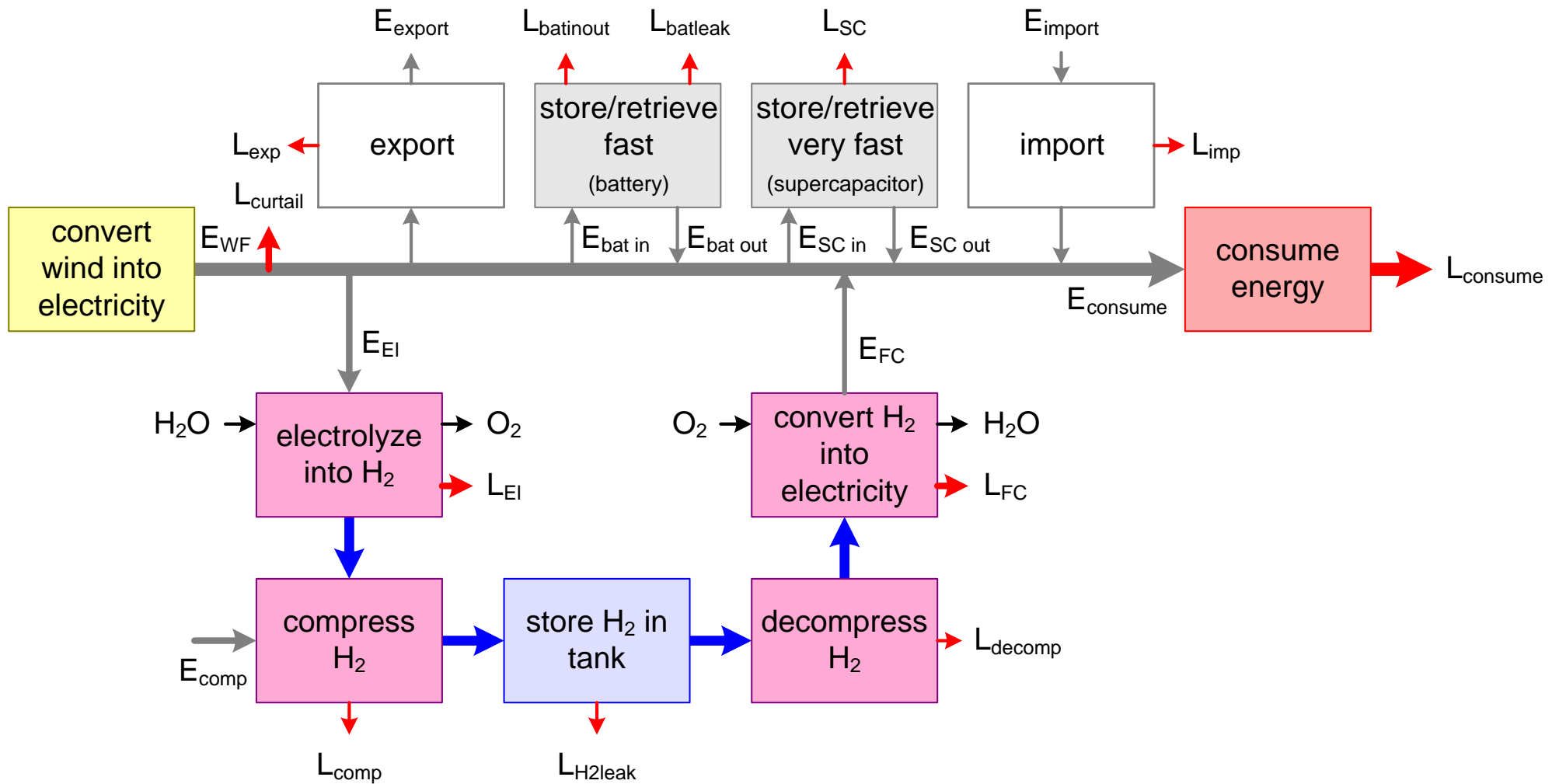
aggregated surplus			
surplus +		surplus -	
	2017	2018	
	583321	337872	-66607
	316200	669854	-64965
	368354	536118	-149616
	209203	310924	-197259
	100599	114026	-191280
	78620	122038	-397491
	49842	125676	-361270
	159892	242967	-204244
	319105	262903	-127673
	425785	389846	-120199
	659014	232856	-29831
	466746	530776	-87566
	3736680	3875856	-1998003

aggregated store/retrieve			
store		retrieve	
	2017	2018	
	291660	168936	-66607
	158100	334927	-64965
	184177	268059	-149616
	104601	155462	-197259
	50300	57013	-191280
	39310	61019	-397491
	24921	62838	-361270
	79946	121483	-204244
	159553	131452	-127673
	212892	194923	-120199
	329507	116428	-29831
	233373	265388	-87566
	1868340	1937928	-1998003

Block Diagram



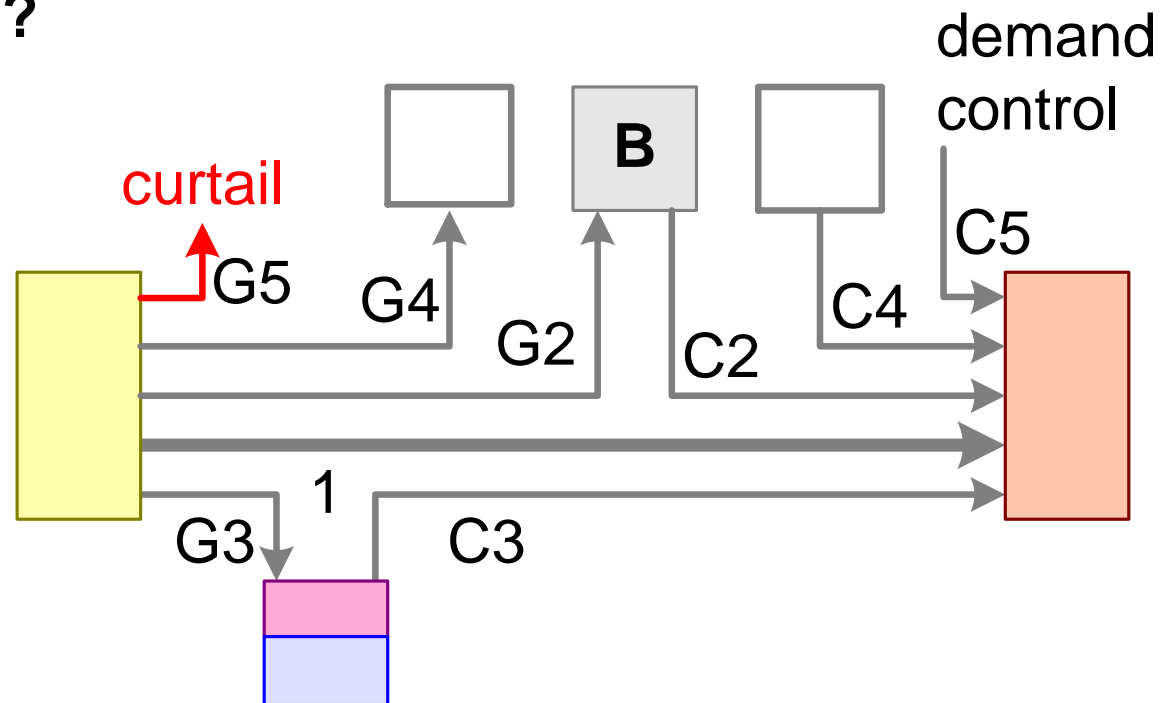
Functional Model



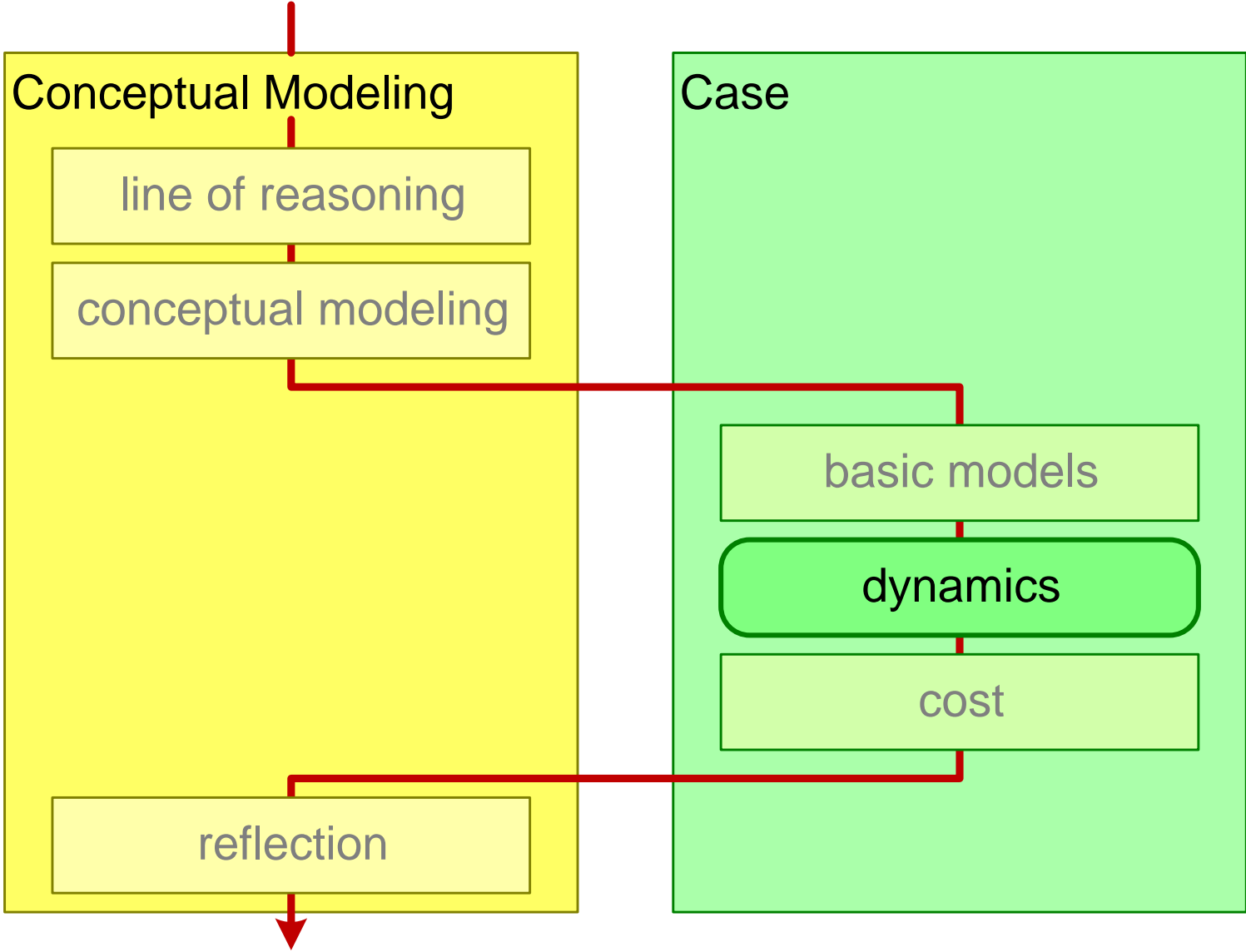
Scenarios for Energy Flows

How to utilize the options?

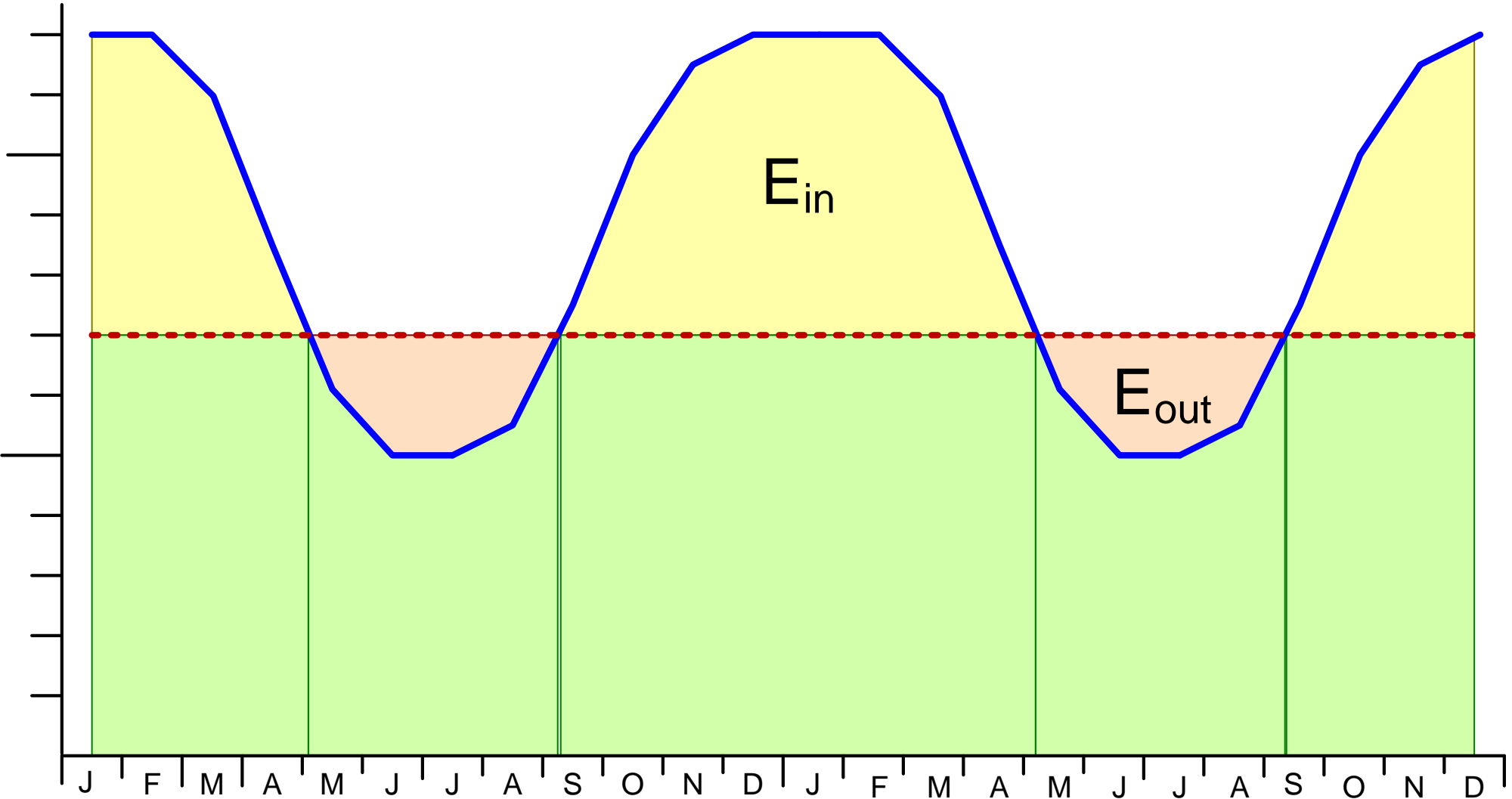
- *direct consumption*
- *battery storage*
- *Hydrogen storage*
- *over-sized generation*
- *import, export*
- *demand control*



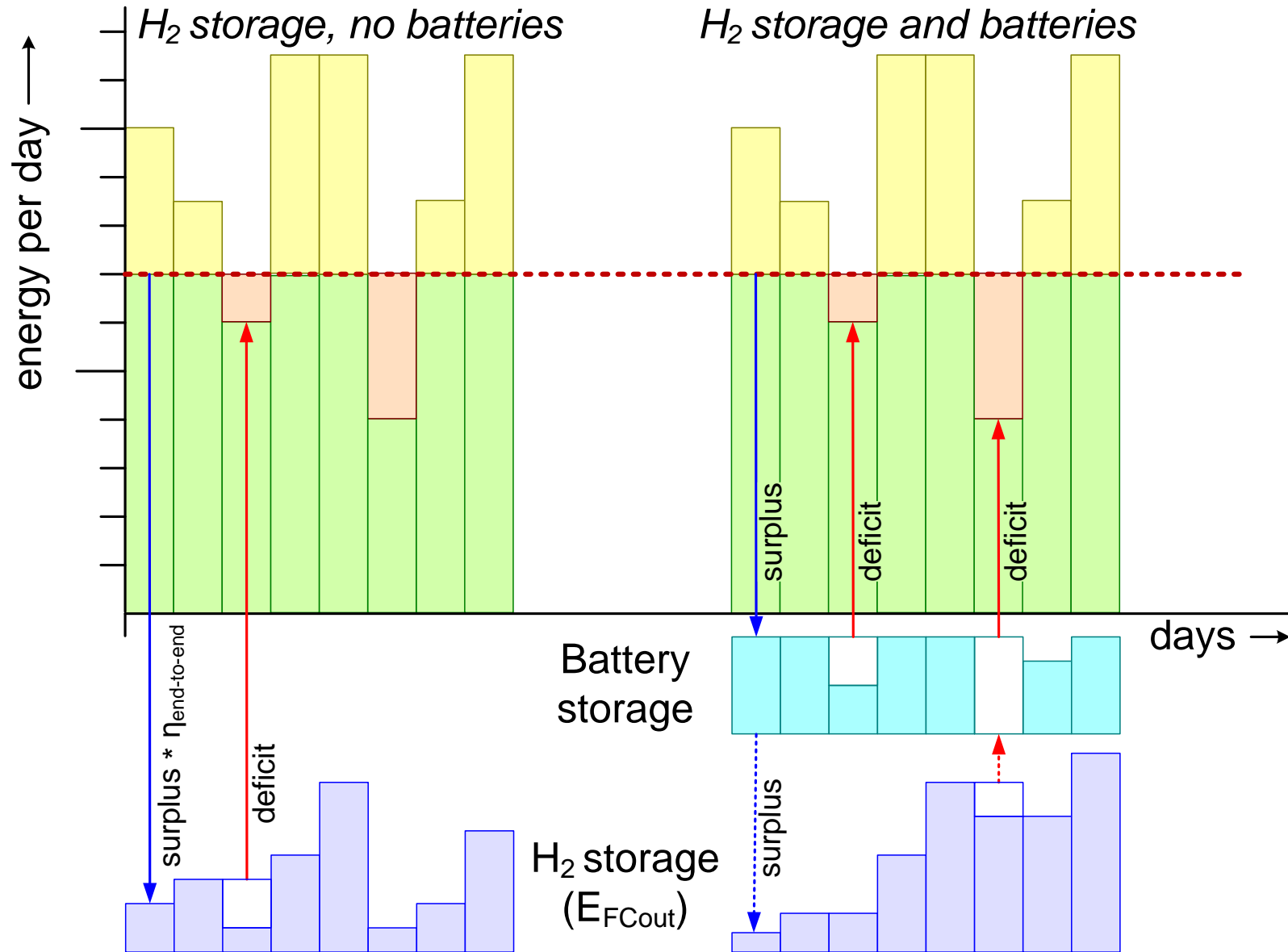
Dynamics



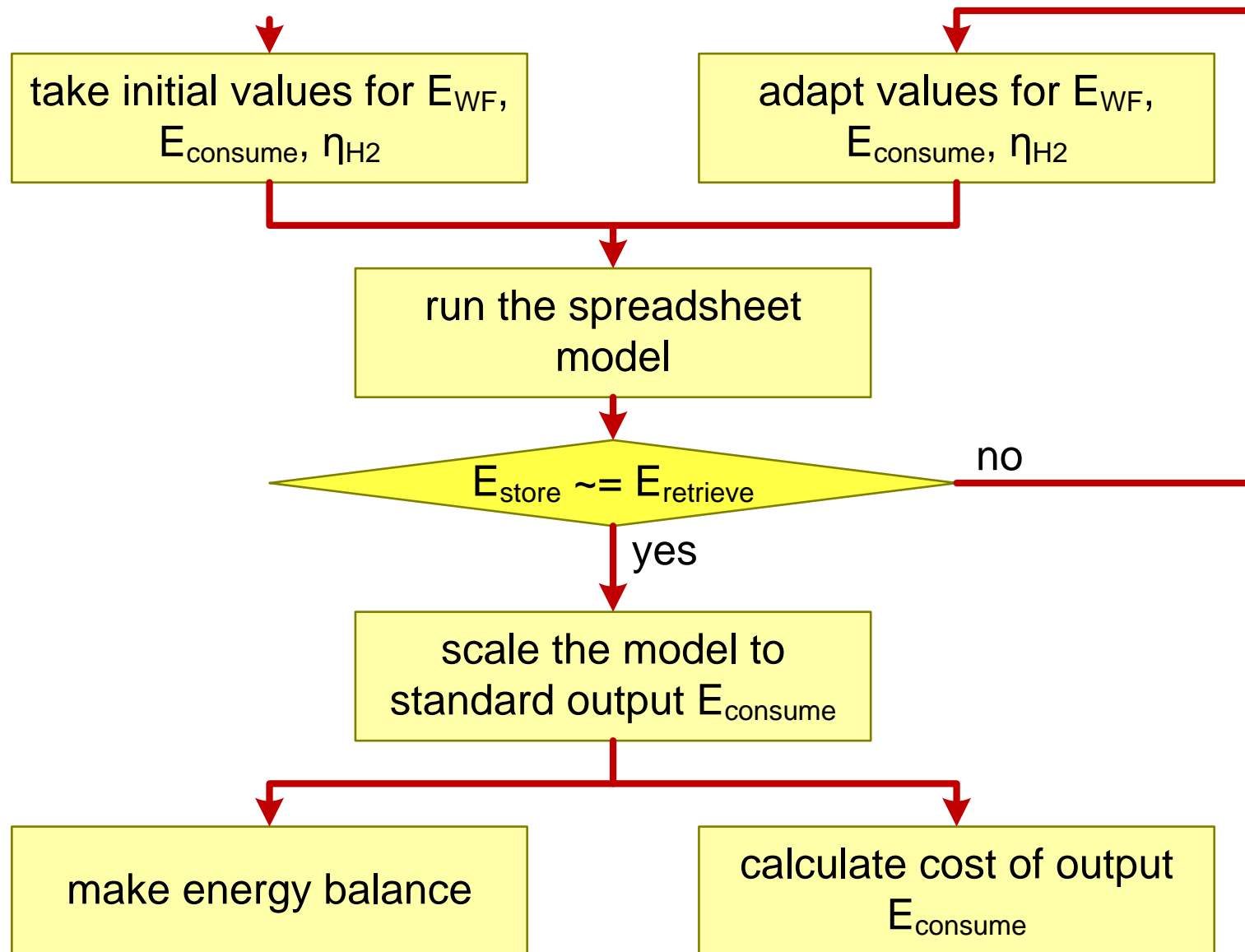
Idealized Production and Consumption



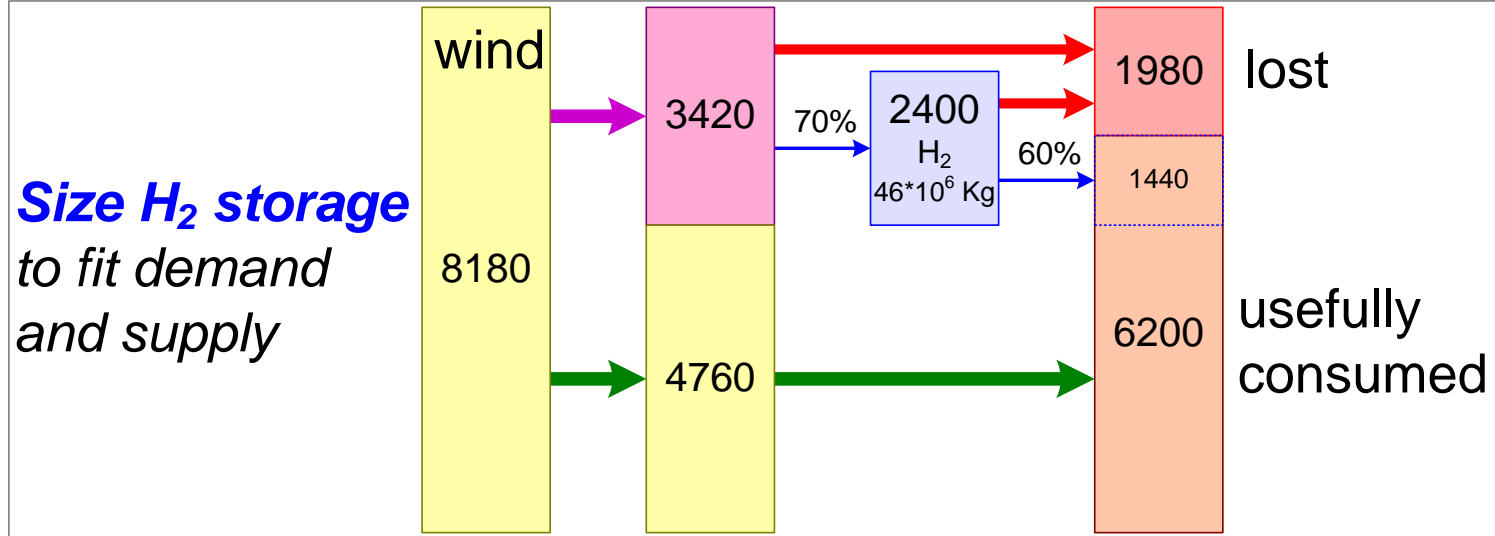
Zooming in on Days



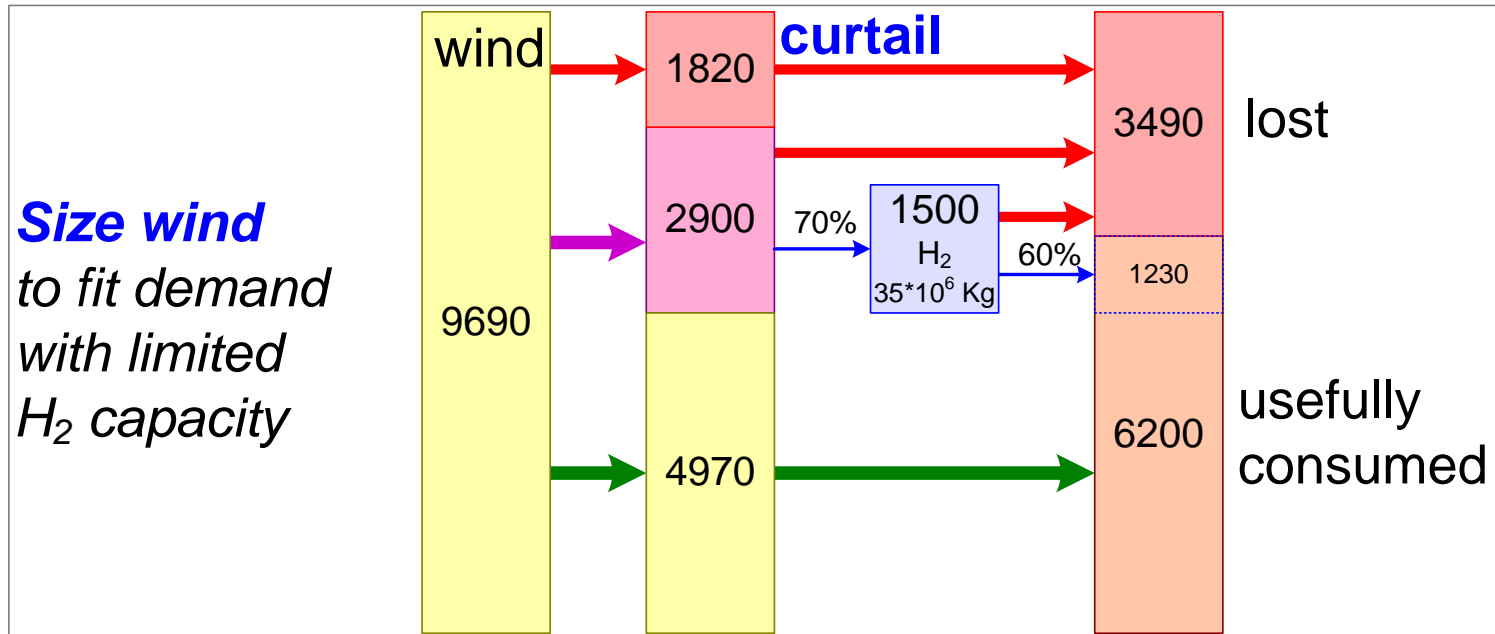
Simulation Workflow

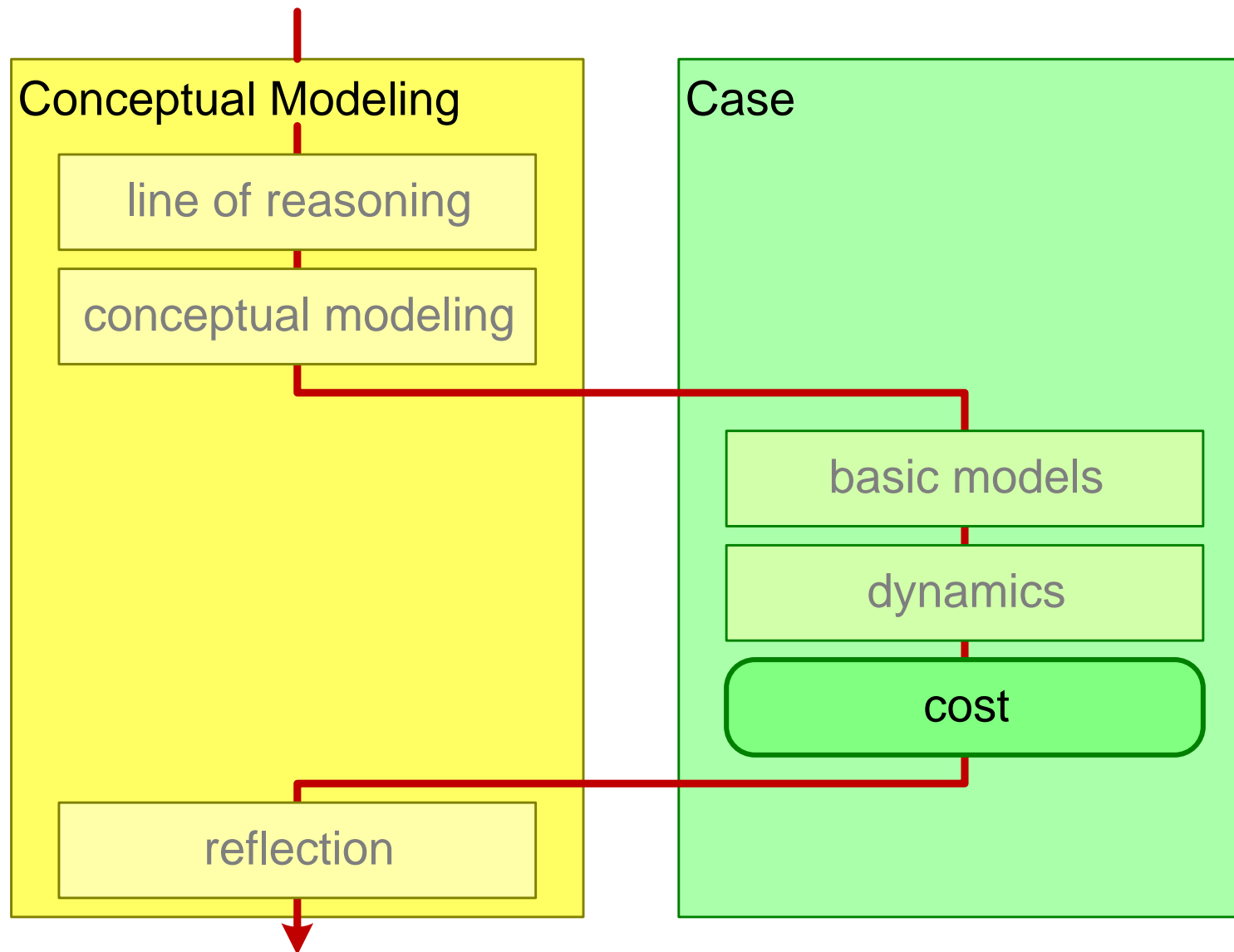


Energy Balance without and with Curtailment

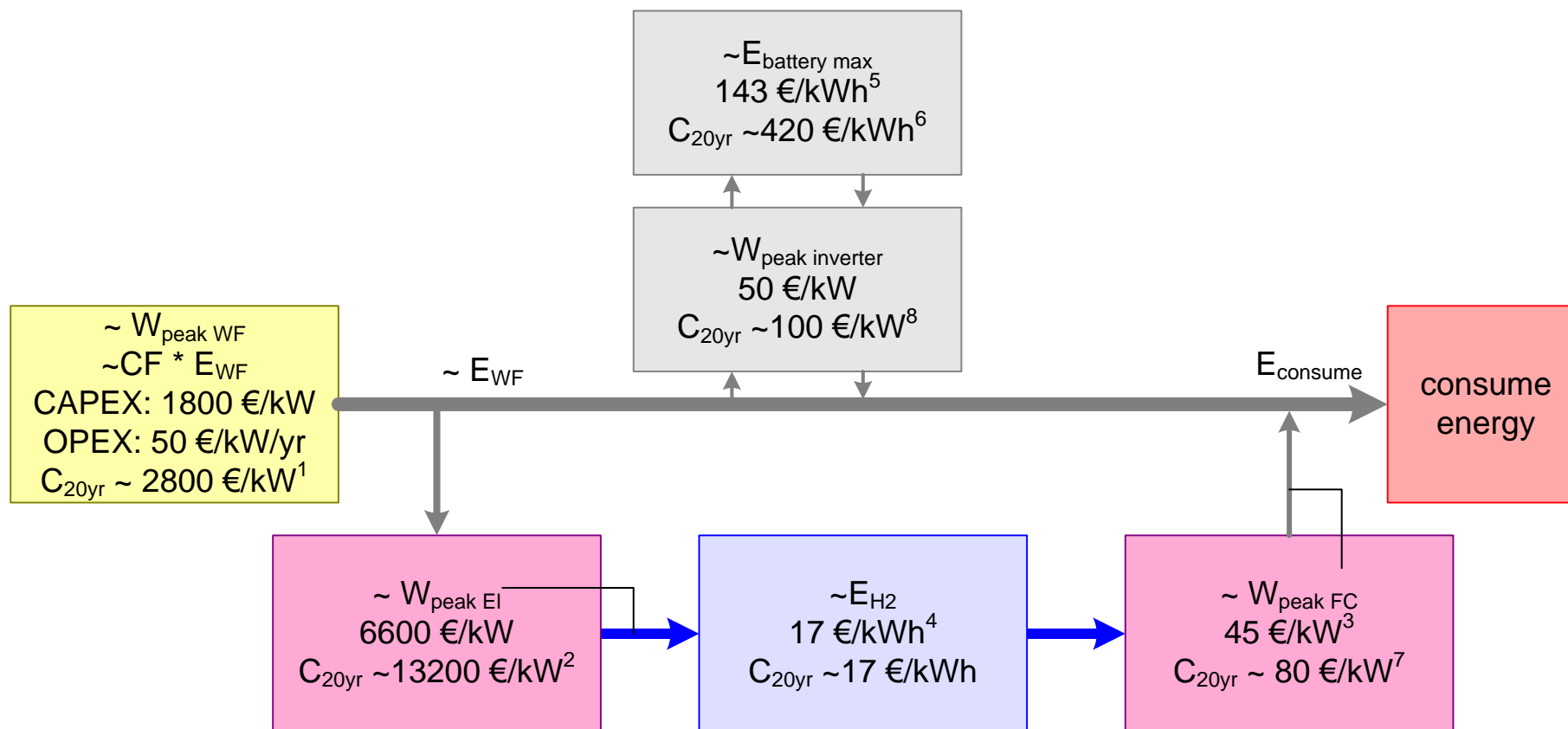


*all numbers
GWh/year*





Cost Model; Guestimates, 2019 data



¹ https://www.pbl.nl/sites/default/files/downloads/pbl-2019-costs-of-offshore-wind-energy-2018_3623.pdf

² using 10 k\$ for 1 KG H₂ in 24 hrs, 33.33kWh/Kg H₂, and 0.92 €/€, 30000 hrs ≈ 10 years <https://pv-magazine-usa.com/2020/03/26/electrolyzer-overview-lowering-the-cost-of-hydrogen-and-distributing-its-productionhydrogen-industry-overview-lowering-the-cost-and-distributing-production/>

³ <https://www.energy.gov/eere/fuelcells/fact-month-april-2018-fuel-cell-cost-decreased-60-2006>

⁴ <https://energypost.eu/the-lowdown-on-hydrogen-part-1-transportation/>

⁵ <https://www.greencarcongress.com/2019/12/20191204-bnef.html>

⁶ 1000 full cycles, let's assume 7 years,

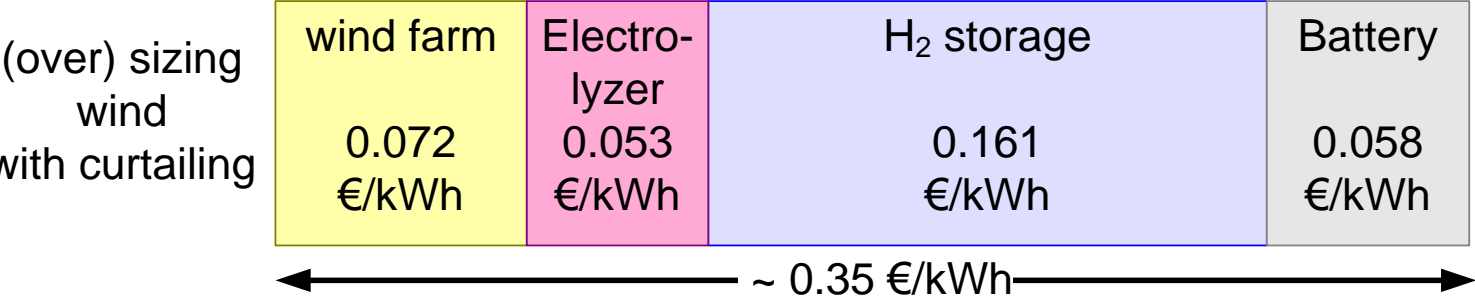
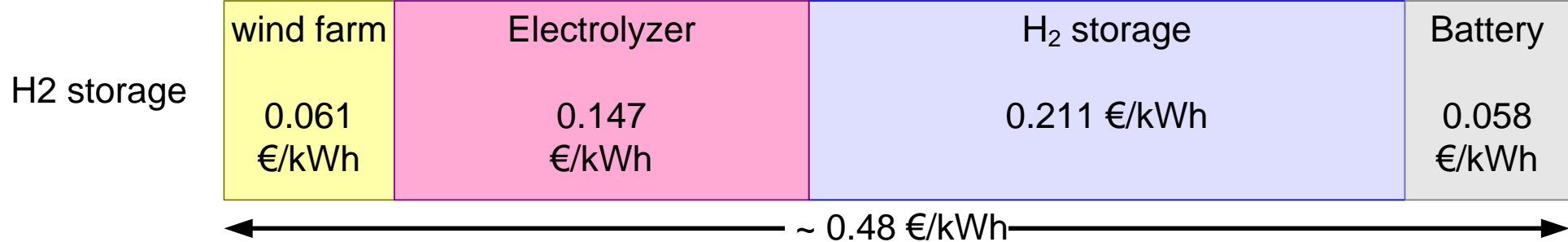
<https://www.forbes.com/sites/arielcohen/2020/12/30/teslas-new-lithium-ion-patent-brings-company-closer-to-promised-1-million-mile-battery/>

⁷ 40000 hours at -35 °C to 40 °C, ~12 years https://en.wikipedia.org/wiki/Fuel_cell

⁸ assuming 10 years <https://www.nrel.gov/docs/fy19osti/72399.pdf>

Energy Cost; Curtailment is Lower in Cost!

assuming 70% * 60% = 42% efficiency
 electrolyzer Fuel Cell



Energy Cost as Function of H2 Size

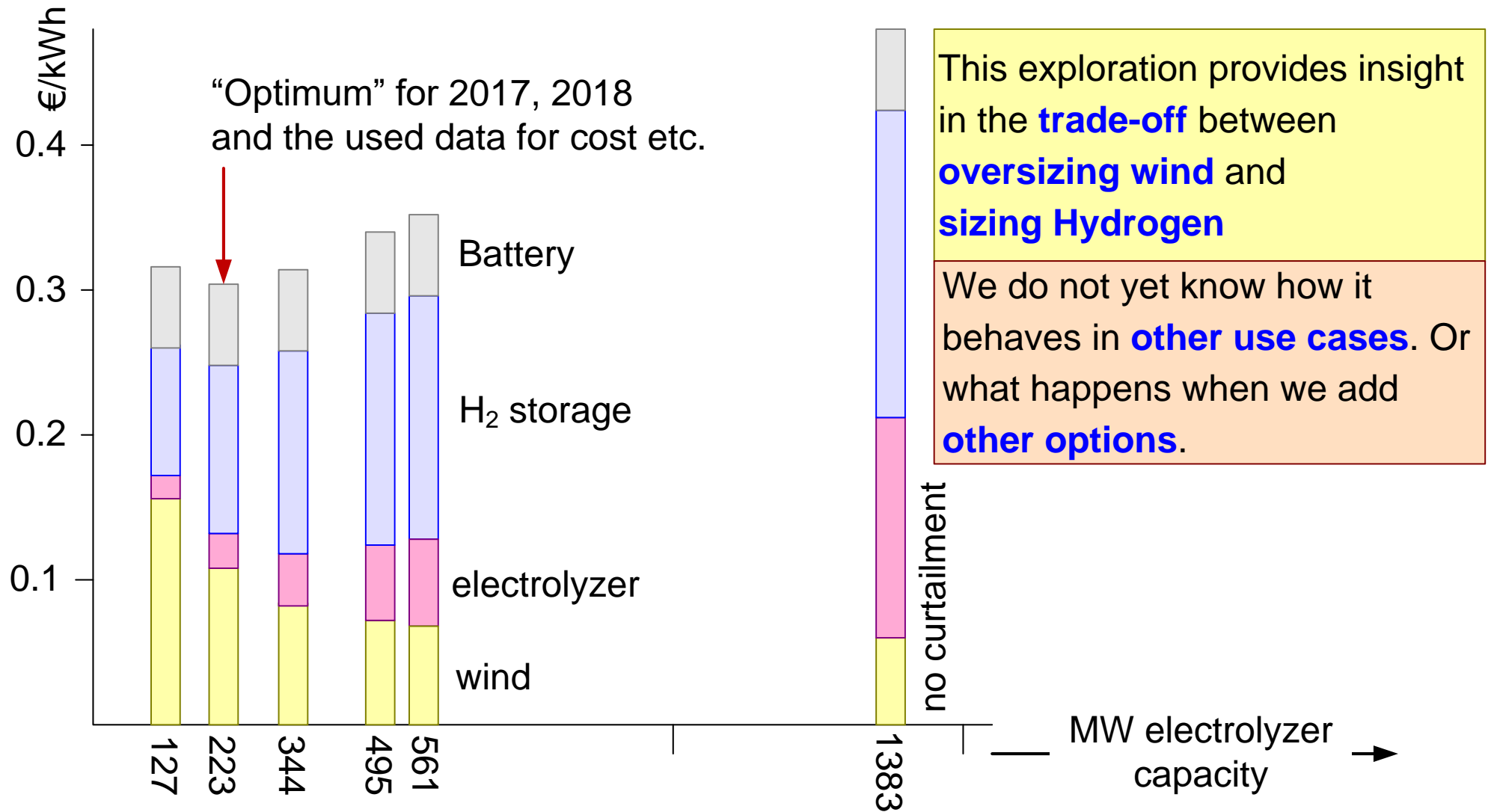
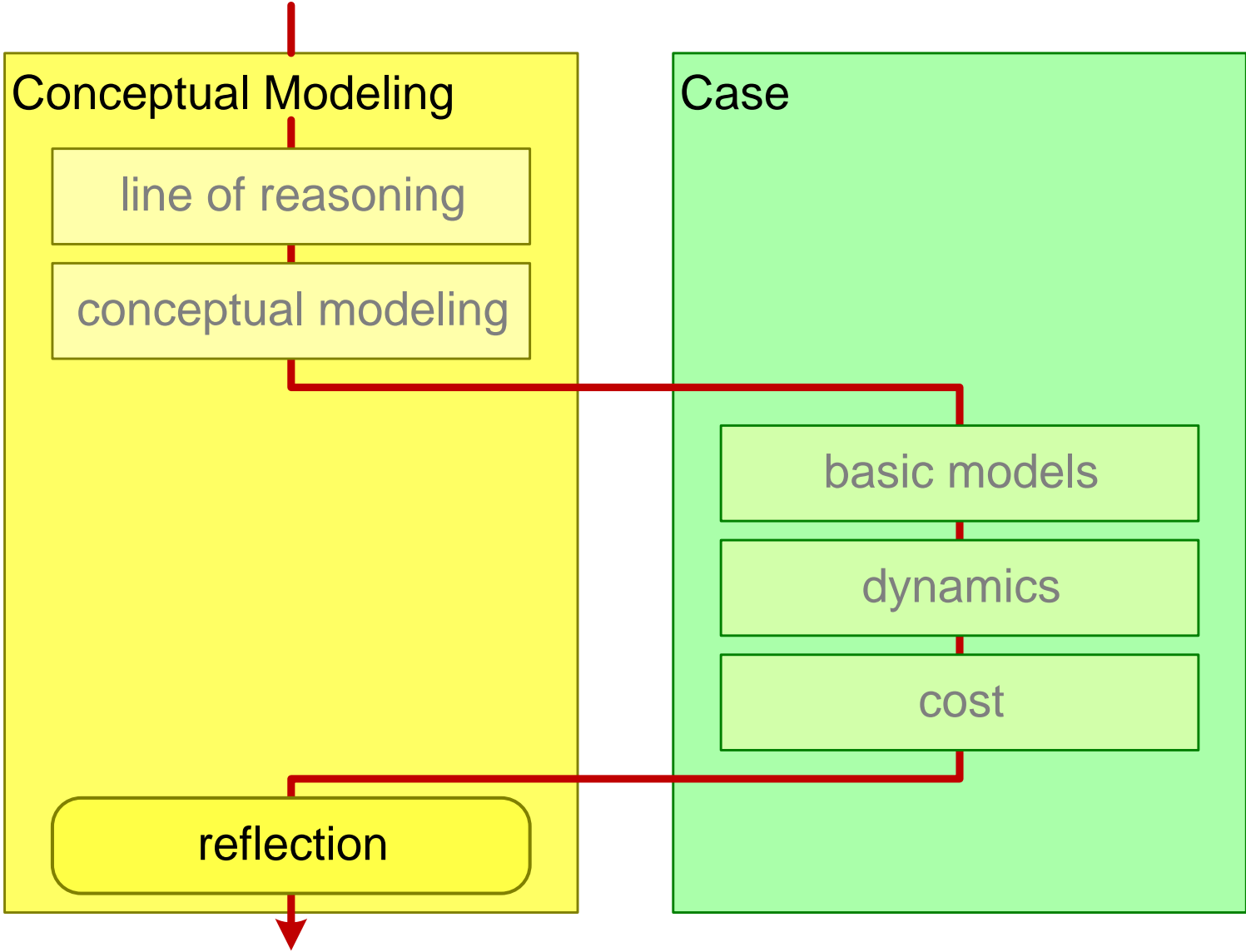


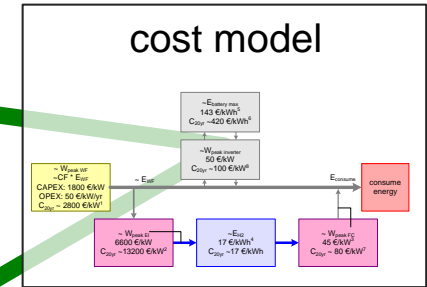
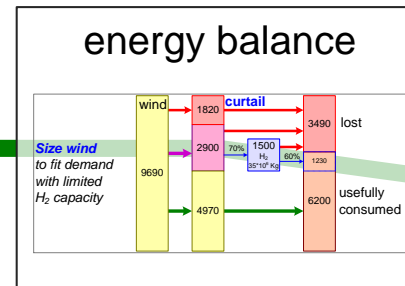
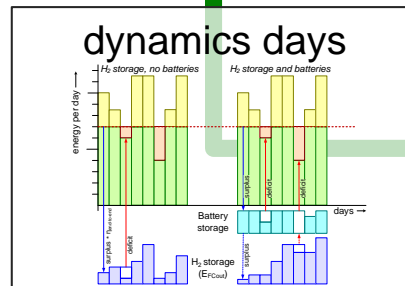
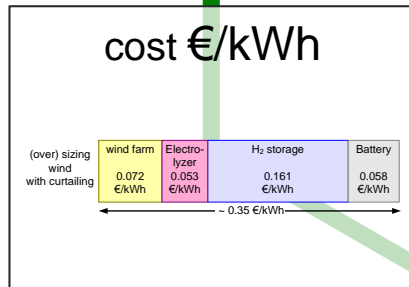
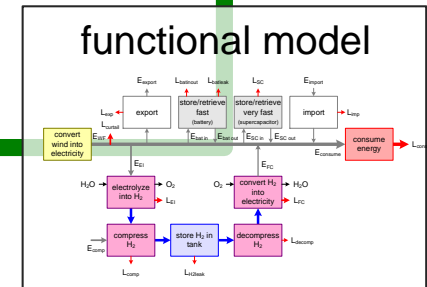
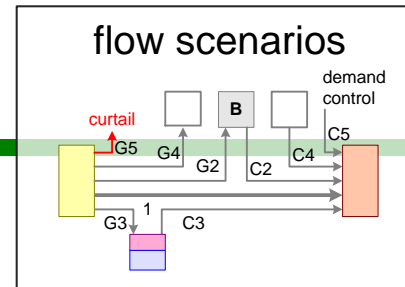
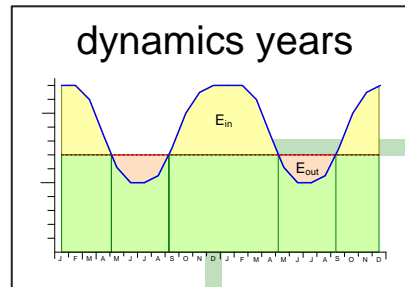
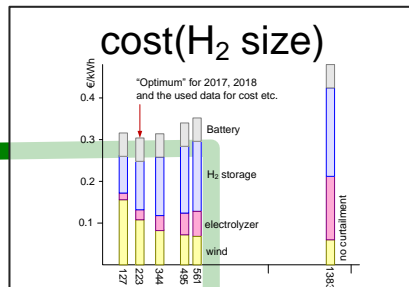
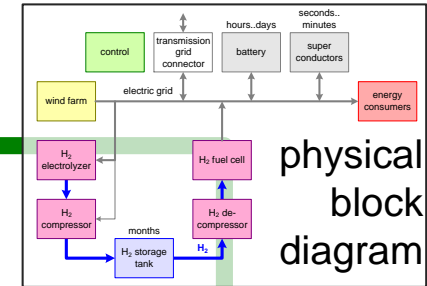
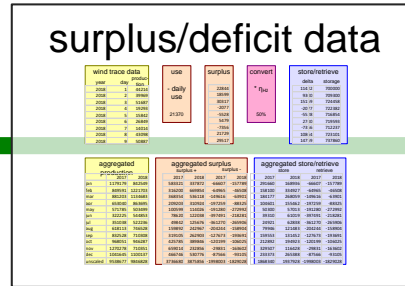
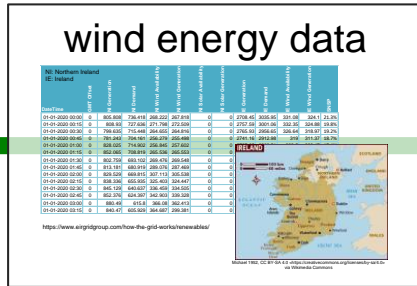
Figure of Content



Case Summary

context and application

design and technology



What Conceptual Modeling brings

- transforming **data** into **insights**
- using **visualizations** to **reason** and to **share**
- using a **wide variety of models**
- grasping the **dynamics** and the **emergent behavior** and **properties**
- translating a **problem** into **needs** into **solution concepts**
- transforming solution concepts into **application consequences**
- and keep **iterating** until sufficient insight is achieved