Flexible Hydrogen Production

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Outline

1. Grey, blue, and green hydrogen. Challenges.
2. Electricity prices today and expectations towards the future.
3. CAPEX today and expectations towards the future. Expected to be halved by 2040.
4. Hydrogen storage. Tank vs. underground.
5. Problem statement.
6. Objective function.
7. Constraints.
8. Results/discussion of results.
9. Hypothetical outcomes. Even more fluctuations? Same fluctuations but lower average price? New pattern?

Energy density

- Potential for storage of energy
- Substantial losses today

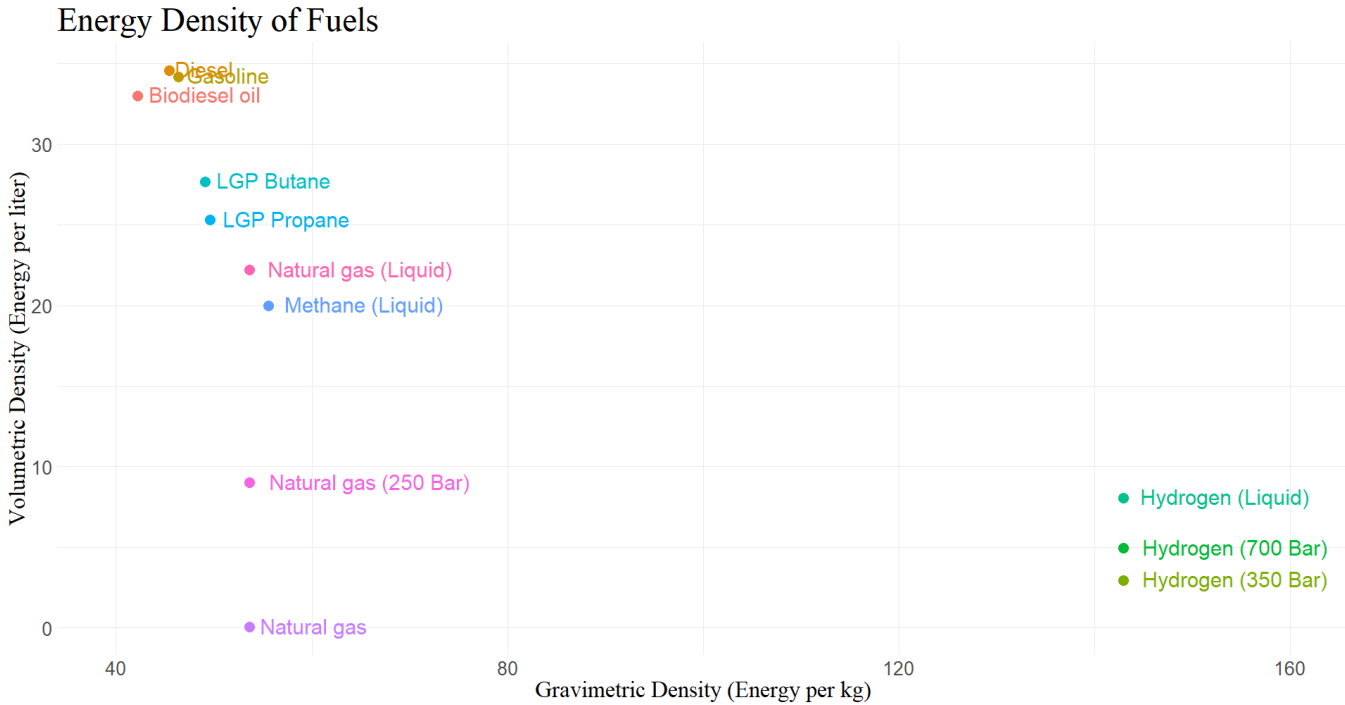

Figure: Energy density of different fuels.

Hydrogen production methods

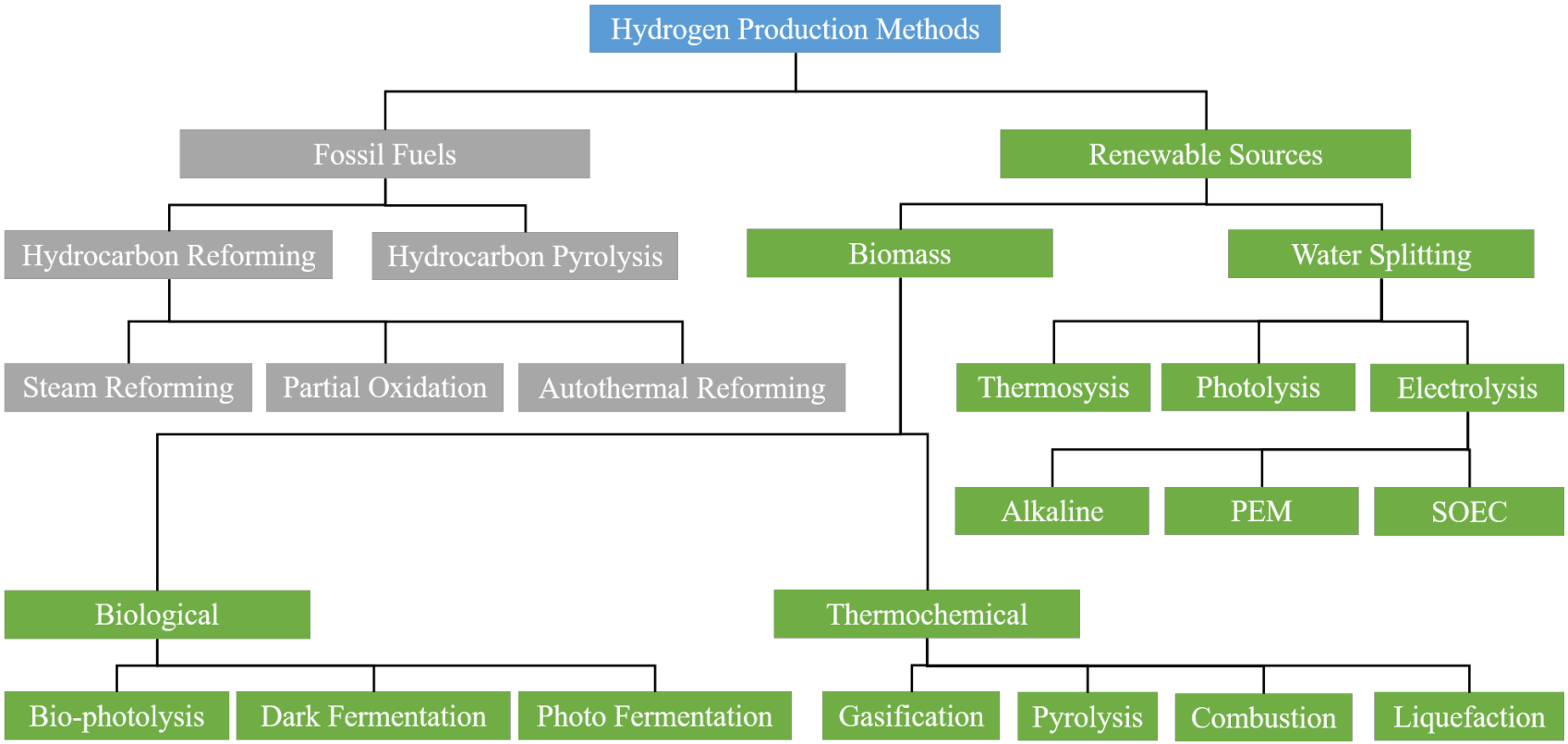

Figure: Overview of different hydrogen production methods.

Hydrogen

- Grey hydrogen
- Blue hydrogen
- Green hydrogen

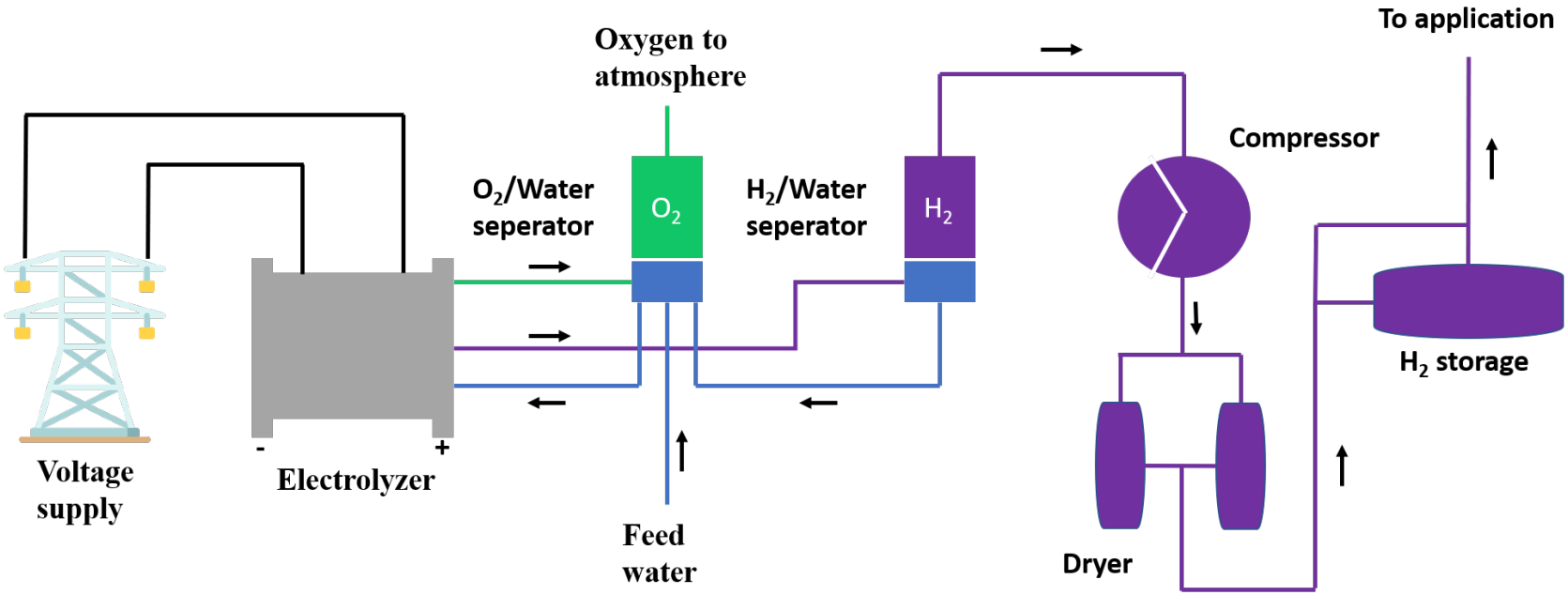

Figure: Water electrolysis production process (NEL, 2019).

Storage methods

- Solid-state
- Tank
- Underground

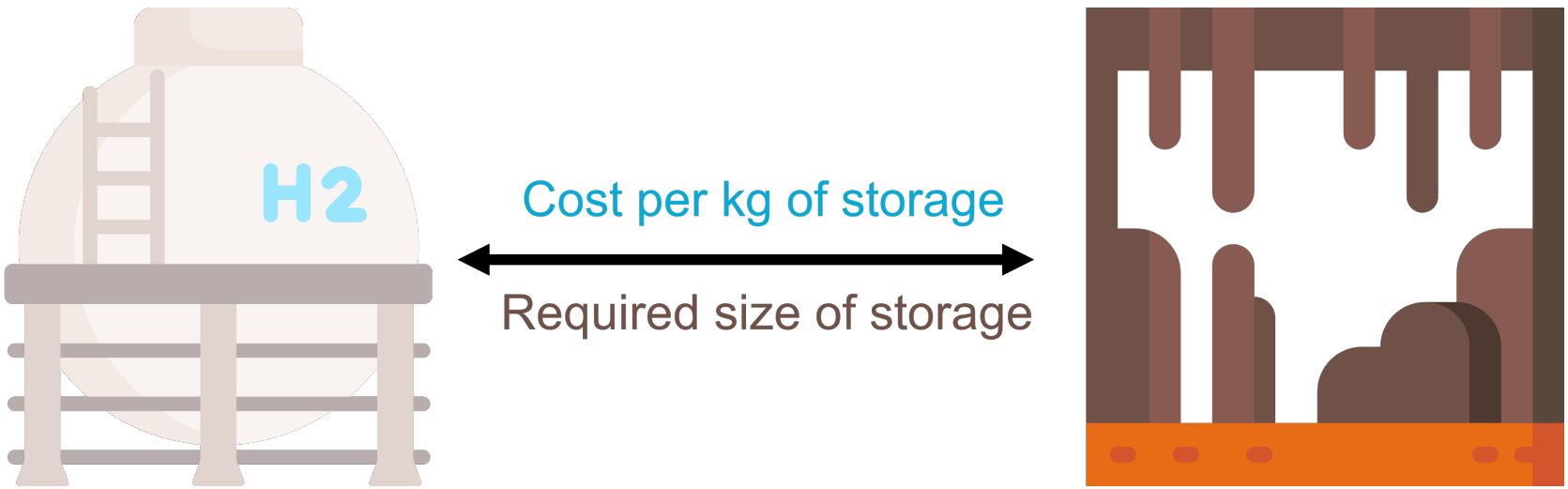

Figure: Trade-offs between tank and underground storage.

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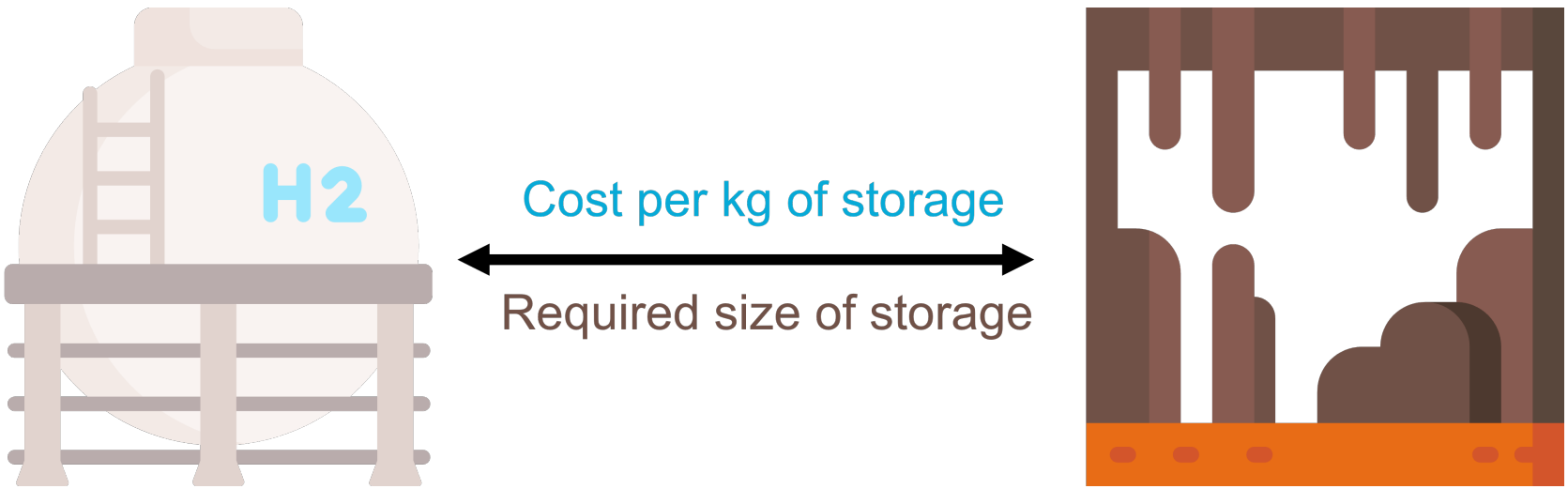

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Electricity prices

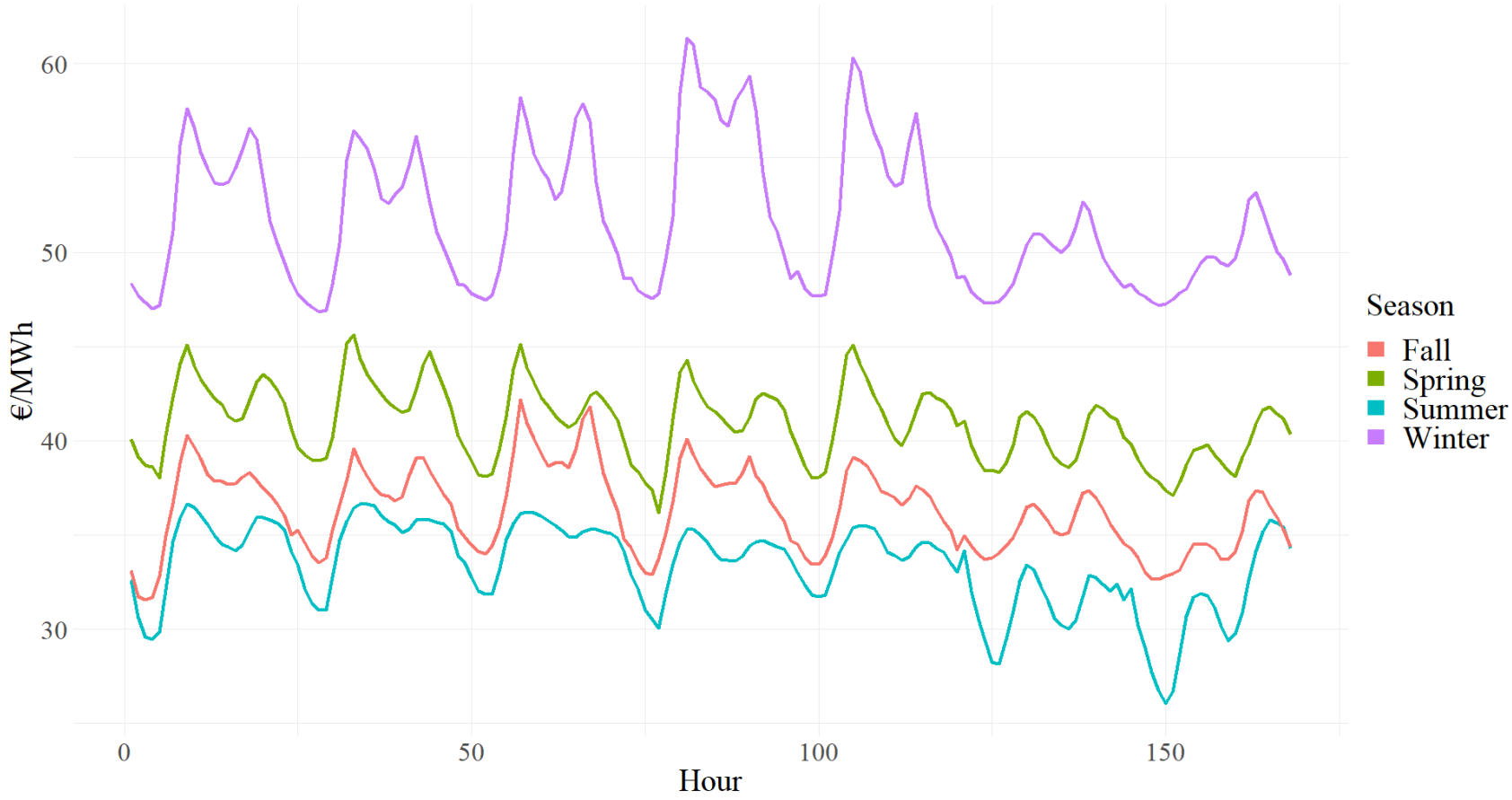

Figure: Aggregated weeks for winter, spring, summer and fall 2019 for Nord Pool NO2 region.

Future electricity prices

- Future electricity prices are expected to increase
- More fluctuations

Year	Statnett (€/MWh)	NVE €/MWh)
2020	28.00	-
2022	-	36.99
2025	34.00	40.93
2030	36.00	39.04
2040	39.00	39.53

Table: Future electricity prices estimates for Southwestern Norway (NO2) from Statnett and NVE [Statnett 2020, NVE 2020]. Note: NVE's estimates are originally denoted in øre/kWh. These are converted to €/MWh with an exchange rate of 0.093 €/NOK.

Electrolyzer CAPEX

- Future electrolyzer CAPEX is expected to decrease substantially

Time horizon	Today	2030	Long term
CAPEX (€/kW)	423-1183	340-723	170-595

Table: Alkaline electrolyzer capital expenditure [IEA 2019]. Note: IEA's estimates are originally denoted in $/kW. These are converted to €/kW with an exchange rate of 1 EUR = 1.21 USD.

Problem statement

We intend to explore if electricity price savings, through the use of excess production capacity and storage, can exceed the associated investment costs.

Objective function

$$\min_{\text{total costs}} \quad \text{total costs} = Capex^{electrolyzer}$$
$$+ Capex^{storage}$$
$$+ \sum_{y \in Y} (Restack_y$$
$$+ Opex_y^{electrolyzer}$$
$$+ Opex_y^{storage}$$
$$+ Grid\_costs_y$$
$$+ \boldsymbol{production\_costs_y}$$
$$+ \boldsymbol{standby\_costs_y}$$
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Constraints

- Capacity
- Production
- Storage/inventory balance
- Equipment states (cold start and standby)
- Non-negativity

Results

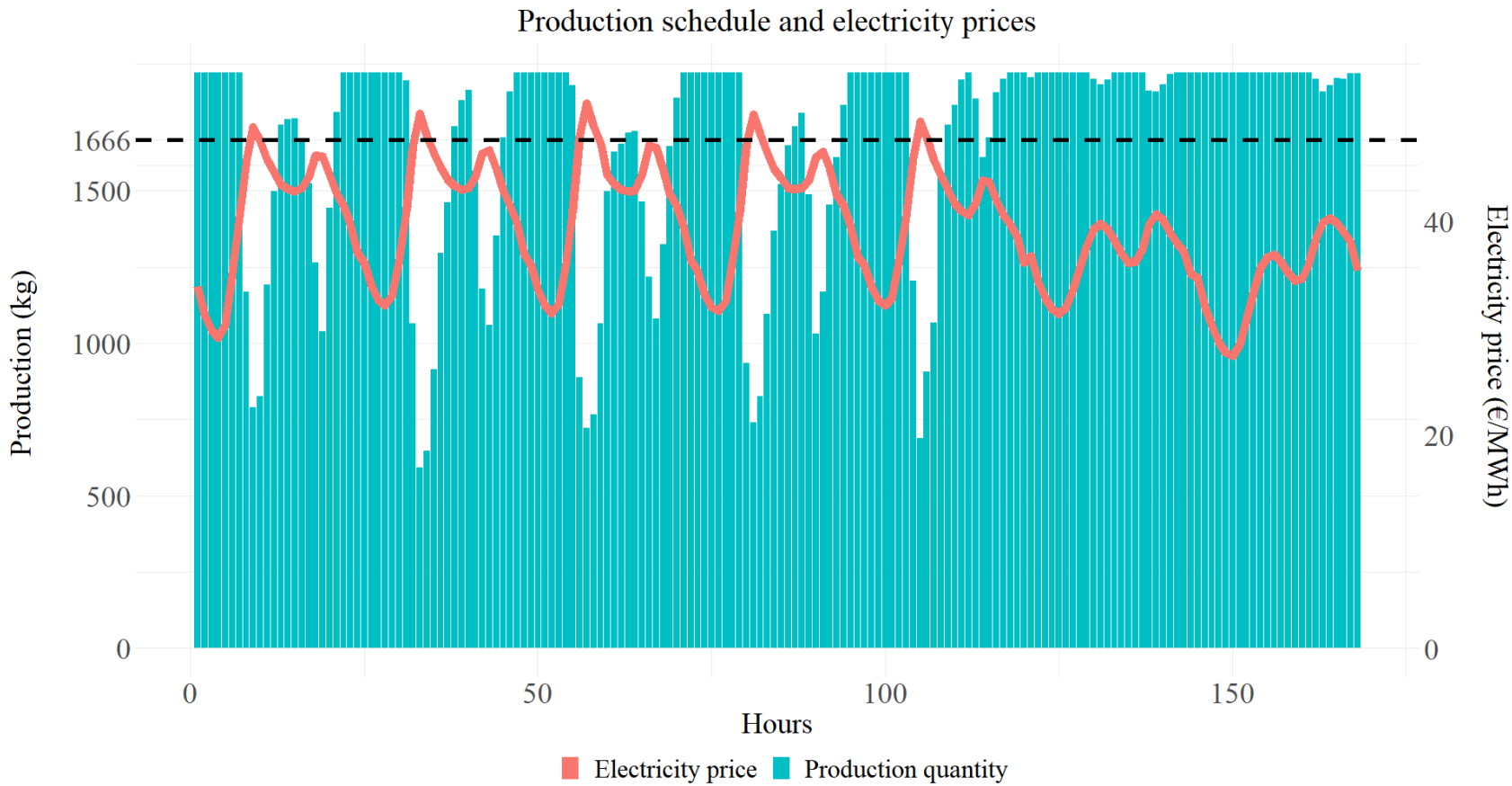

Figure: Hourly, weekly average, production schedule and electricity prices in a future scenario. Daily off-take: 40 tonnes, daily production capacity: 47 tonnes, storage capacity: 500 tonnes.

Results

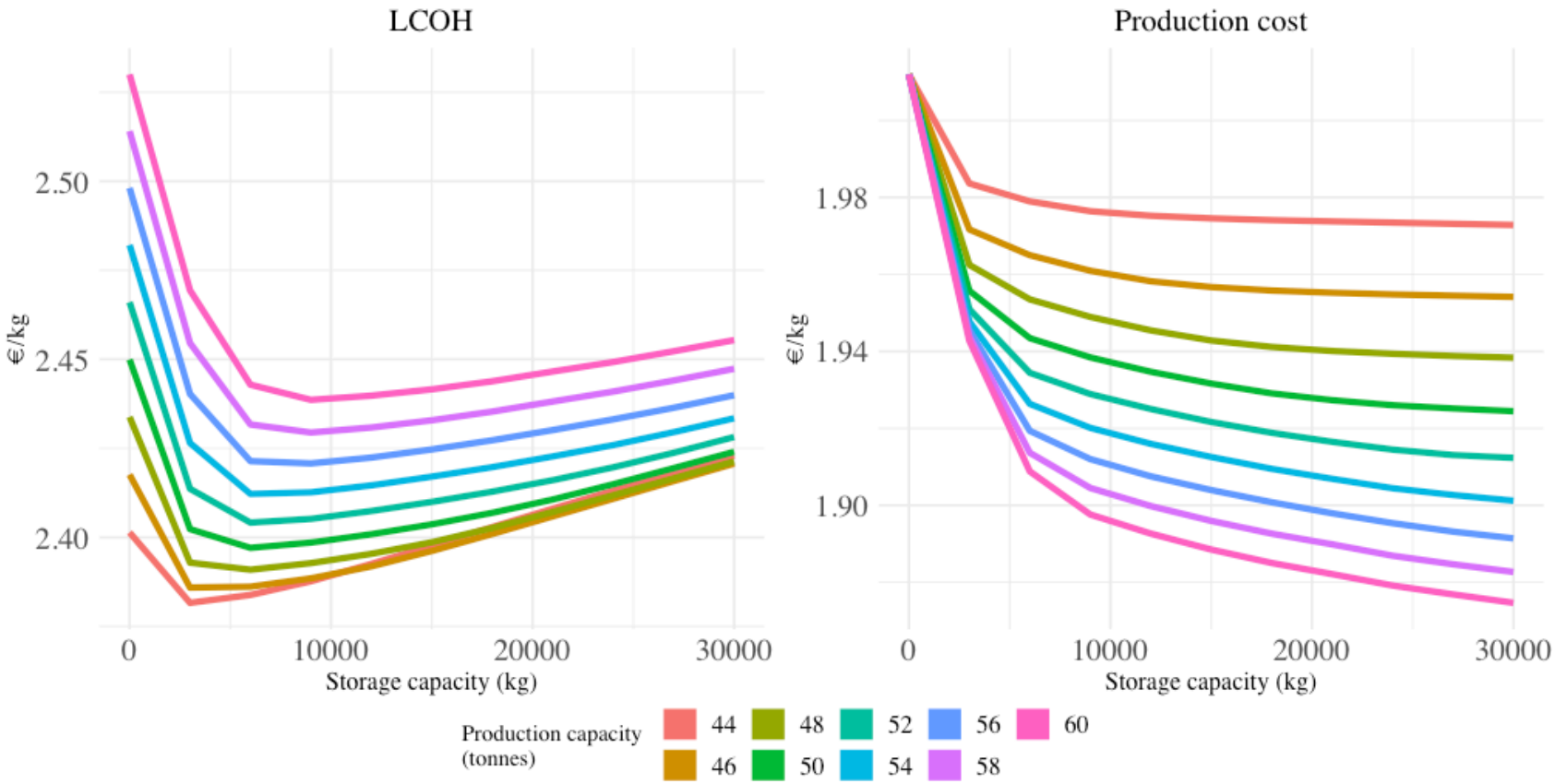

Figure: LCOH (€/kg) and production cost (€/kg) for different production and storage capacities in scenario 3 (long-term time horizon). Daily off-take: 40 tonnes.

Results

- Excess production capacity (>44 tonnes) is only applicable in the long-term with underground storage when considering grid-connected water electrolysis

Scenario	Production capacity	Storage capacity	LCOH	Production cost
1	44	3,000	3.016	2.307
2	44	3,000	2.657	2.133
3	44	3,000	2.382	1.984
4	44	500,000	2.620	1.978
5	47	500,000	2.337	1.793

Table: Optimal daily production capacity (tonnes), storage capacity (kg), LCOH (€/kg) and production cost (€/kg). Scenario 1 reflects today, scenario 2 and 4 reflect medium-term, and scenario 3 and 5 reflect long-term. Daily off-take: 40 tonnes.

Comparing results with and without grid fees

- Daily production capacity increases more (and earlier) without the impact of grid fees
- Flexible hydrogen production can be preferred for off-grid electrolysis in the long-term

	With grid fees				Without grid fees			
	Production capacity	Storage capacity	LCOH	Production cost	Production capacity	Storage capacity	LCOH	Production cost
1	44	3,000	3.016	2.307	44	3,000	2.717	2.218
2	44	3,000	2.657	2.133	44	3,000	2.379	2.050
3	44	3,000	2.382	1.984	53	6,000	2.114	1.854
4	44	500,000	2.620	1.978	48	500,000	2.350	1.868
5	47	500,000	2.337	1.793	60	500,000	2.064	1.647

Table: Optimal daily production capacity (tonnes), storage capacity (kg), LCOH (€/kg) and production cost (€/kg) in scenarios 1-5 with and without grid fees. Daily off-take: 40 tonnes.

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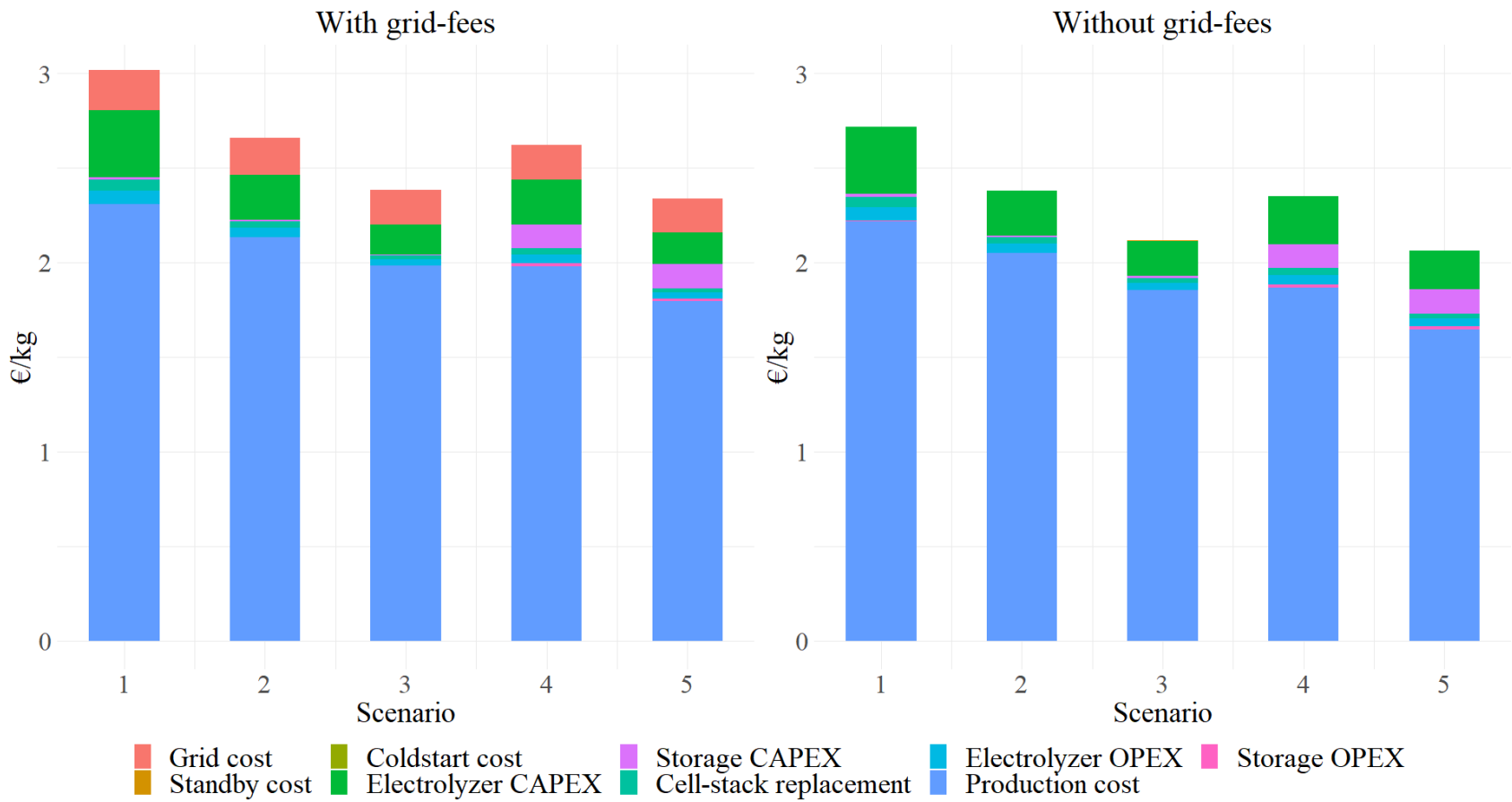

Figure: Stacked LCOH with and without grid fees.

Key takeaways

- Challenging to make production scheduling profitable today
- Large underground facilities are required
- Grid fees limit the potential, both today and in the future
- Off-grid/subsidized water electrolysis
- Competitiveness with blue hydrogen?

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Selected references

Statnett (2020)
Langsiktig markedsanalyse: Norden og Europa 2020-2050

NVE (2020)
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IEA (2019)
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