Decentralized Cogeneration (Flexible Swarms) for Buildings, Industry and Mobility Services

Gil Georges, Konstantinos Boulouchos, Philipp Vögelin

Outline: integrating heat, electricity and mobility services

→ exploiting bioenergy CO_2 mitigation potential

Switzerland has a finite, sustainable bioenergy potential

- How to maximize its CO_2 mitigation potential?

Different paths, including transport:

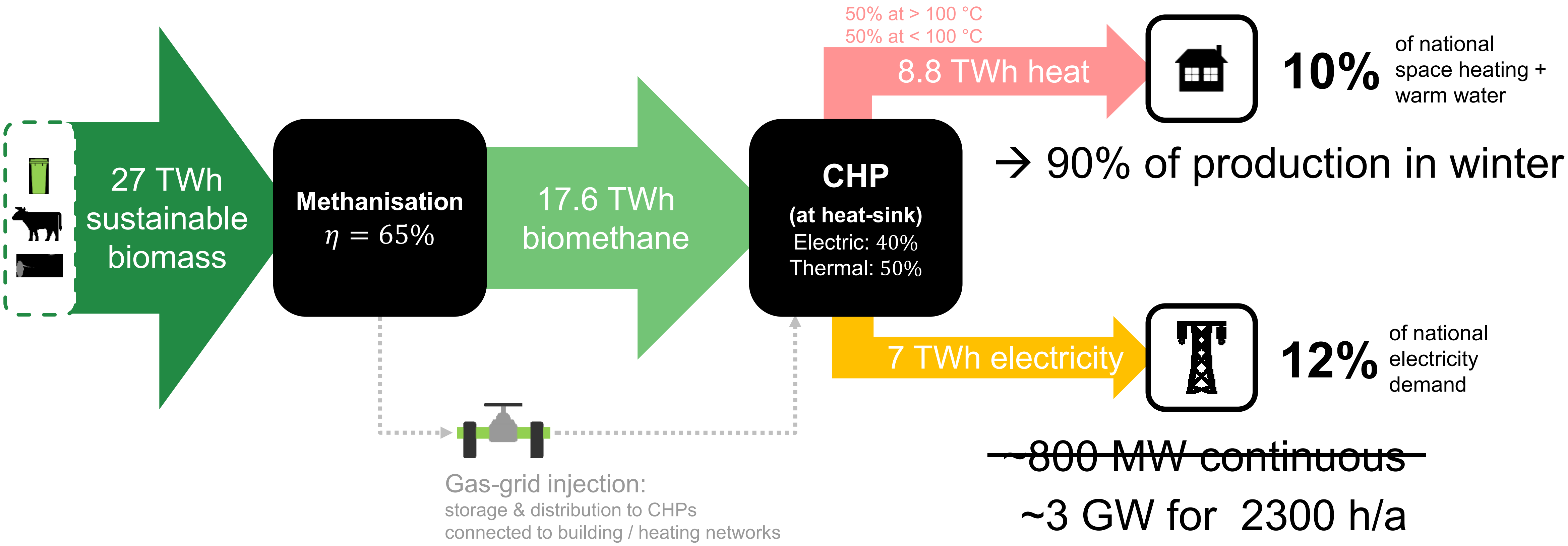
1. Biogenic CHP swarm → biogas for seasonal balancing of PV
2. Use as substitute fuel in transport, particularly long-range
3. CHP for all-year industrial heat demand + e-mobility
4. Biogenic CHP swarm for e-mobility

Disclaimer: not considered:

- Policy and economic constraints
- Life-cycle emissions / energy
- Certain technical constraints (grid, mobility patterns, availability of heat sinks)

CHPswarm: biomethane in distributed CHP for heat and power

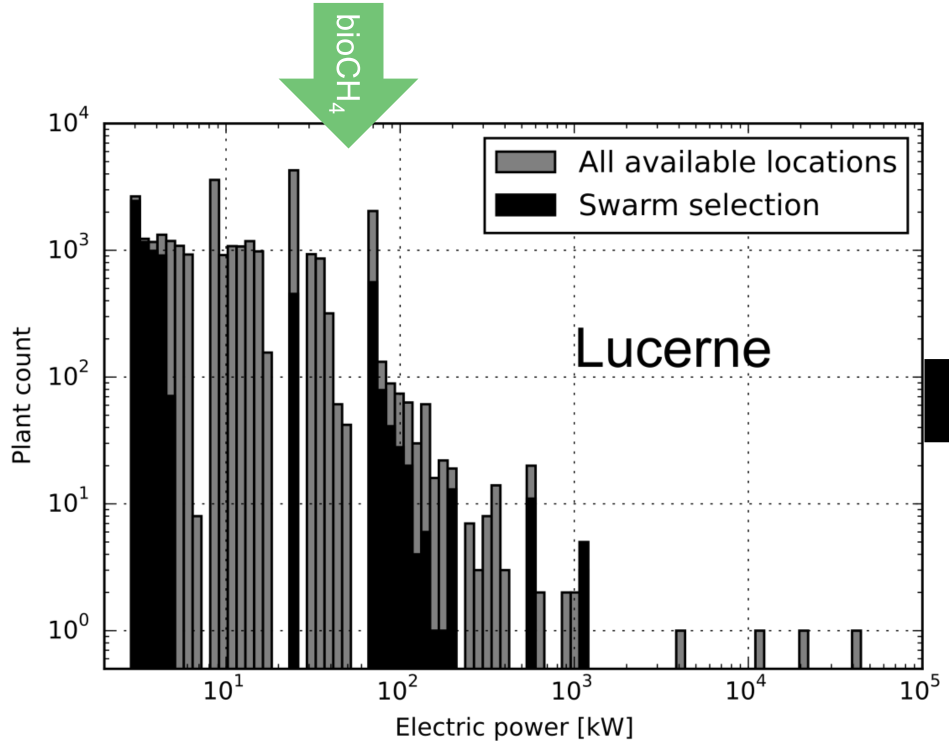
Maximally use biogenic potential using gas-grid as distribution and storage system

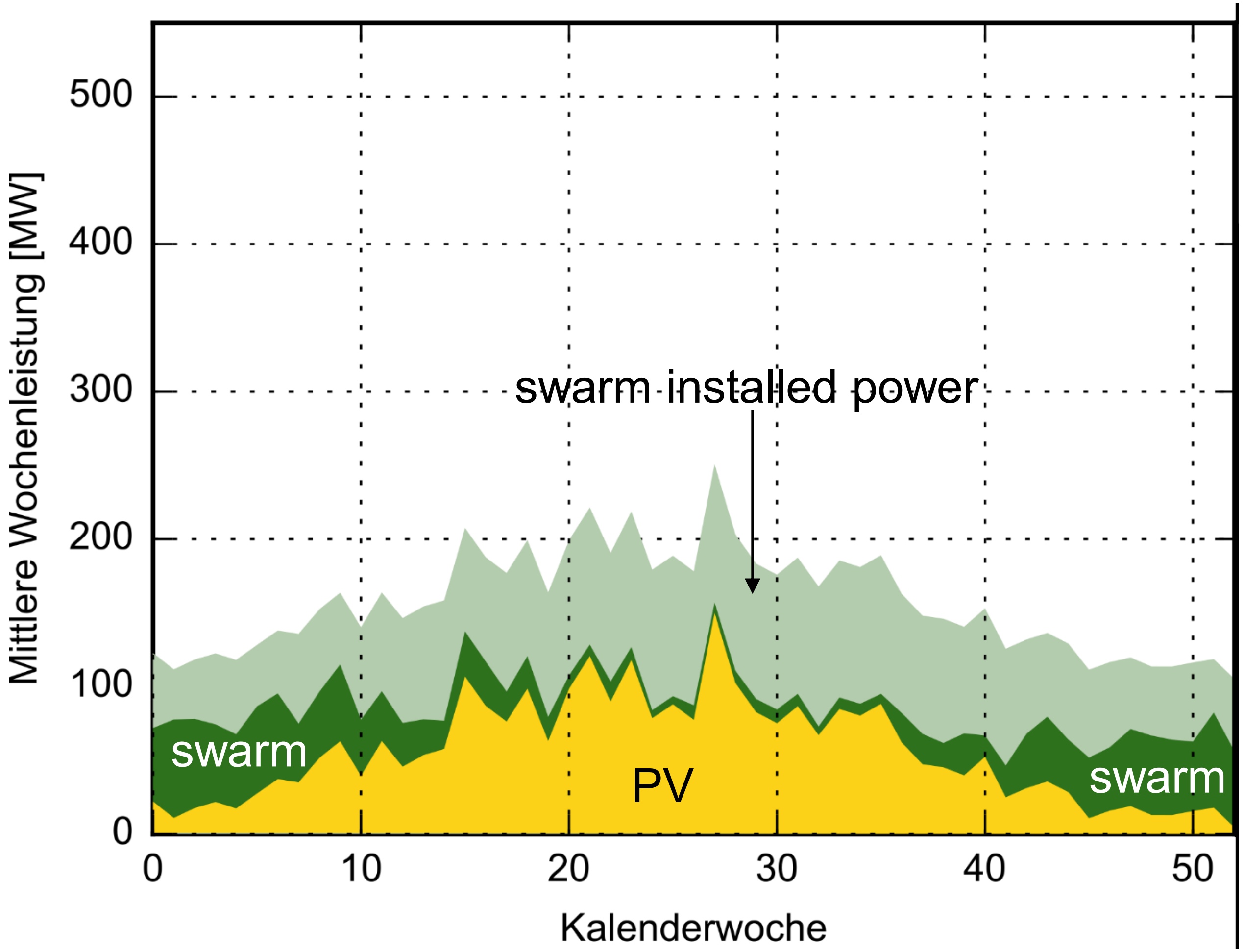


Hypothesis: future energy systems, dominated by PV, require significant sustainable, dispatchable power

Electricity production → Example: Region of the size of Lucerne

Natural PV compensation, but residential buildings reduce dispatchability during summer





What if there is no need for large dispatchable power reserves?

→ alternative, speculative story-lines involving mobility

“CHPswarm”

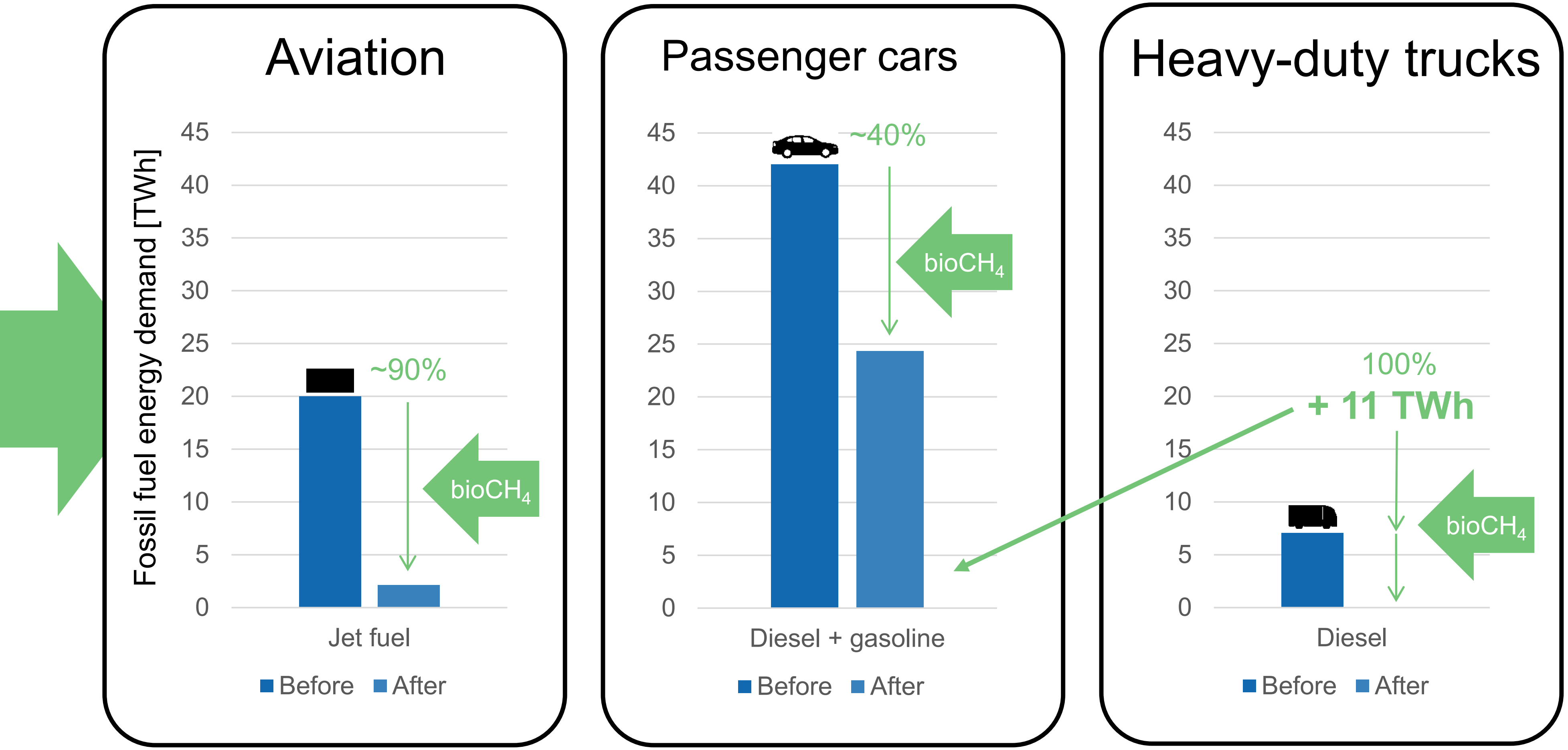
CHP + seasonal storage
via gas-grid

“direct”

Biomethane as
substitute fuel

CO_2 reduction potential of "direct" route

→ assuming same efficiencies and same vehicle mass, only a matter of substitutable energy



For reference (BAFU)
road: ~15 Mt CO_2/a
road + aviation: 21 Mt/a

$$-4.4\ Mt/a$$

(for trucks only if remaining biogas used elsewhere, e.g. in passenger cars)

Assuming same efficiency and weight of gas-ICE powertrain and disregarding any technical limitations, such as range

What if long-range transport is electrified by other means?

→ powering e-mobility using biogenic CHPs

"CHPswarm"

CHP + seasonal storage
via gas-grid

"CHP e-mobility"

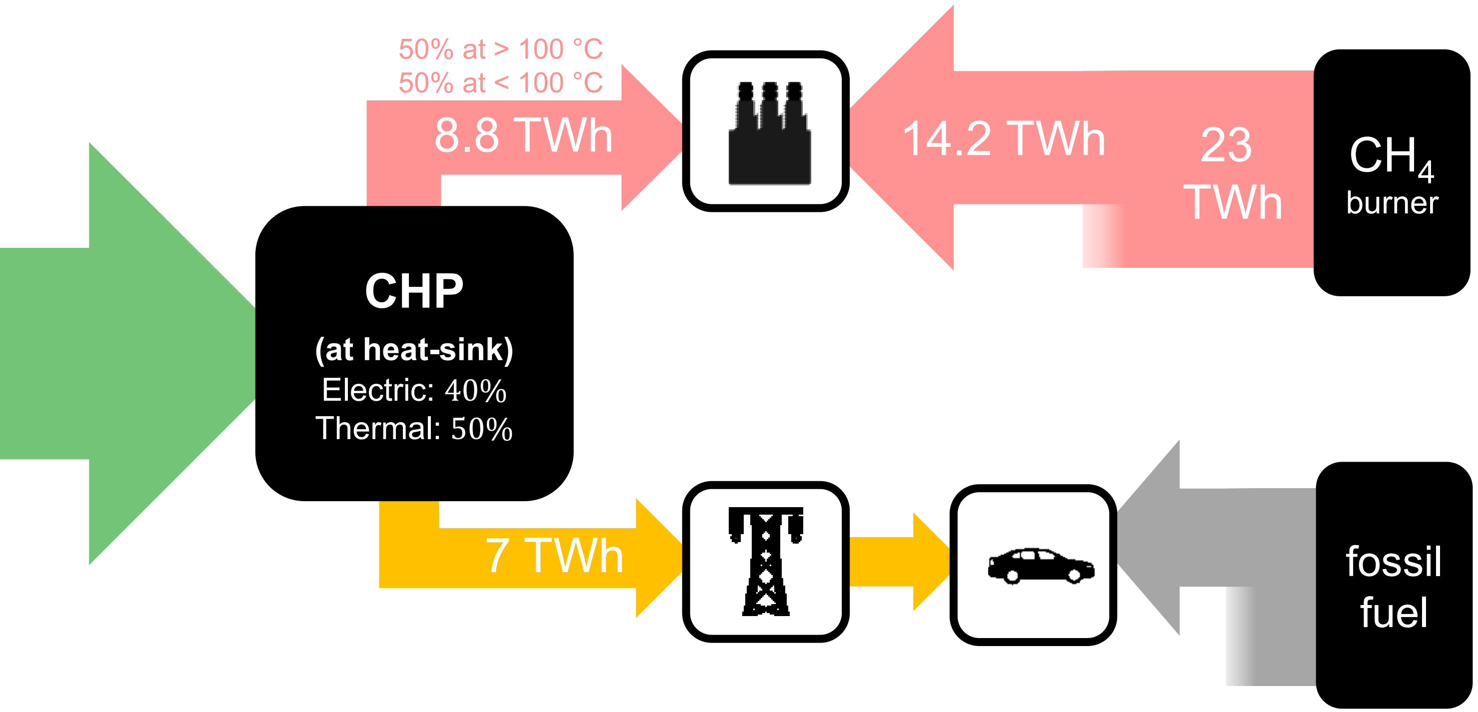
Electric mobility powered by
continuous CHP power
heat: high-temp. industrial processes

"direct"

Biomethane as
substitute fuel

Using 8000+ h/a CHP to power e-mobility

Advantage → higher CO_2 reduction due to utilization of heat



- Industrial heat demand: 23 TWh/a *not electrifiable via heat-pumps* (SCCER EIP)
- CO_2 avoidance → **1.9 Mt/a**

- Full electrification of Swiss passenger car fleet: 14 TWh/a (SCCER mobility)
- Currently emissions: 10.2 Mt/a (BAFU)
- CO_2 avoidance → **5.1 Mt/a**

$$\approx -7.0\ Mt/a$$

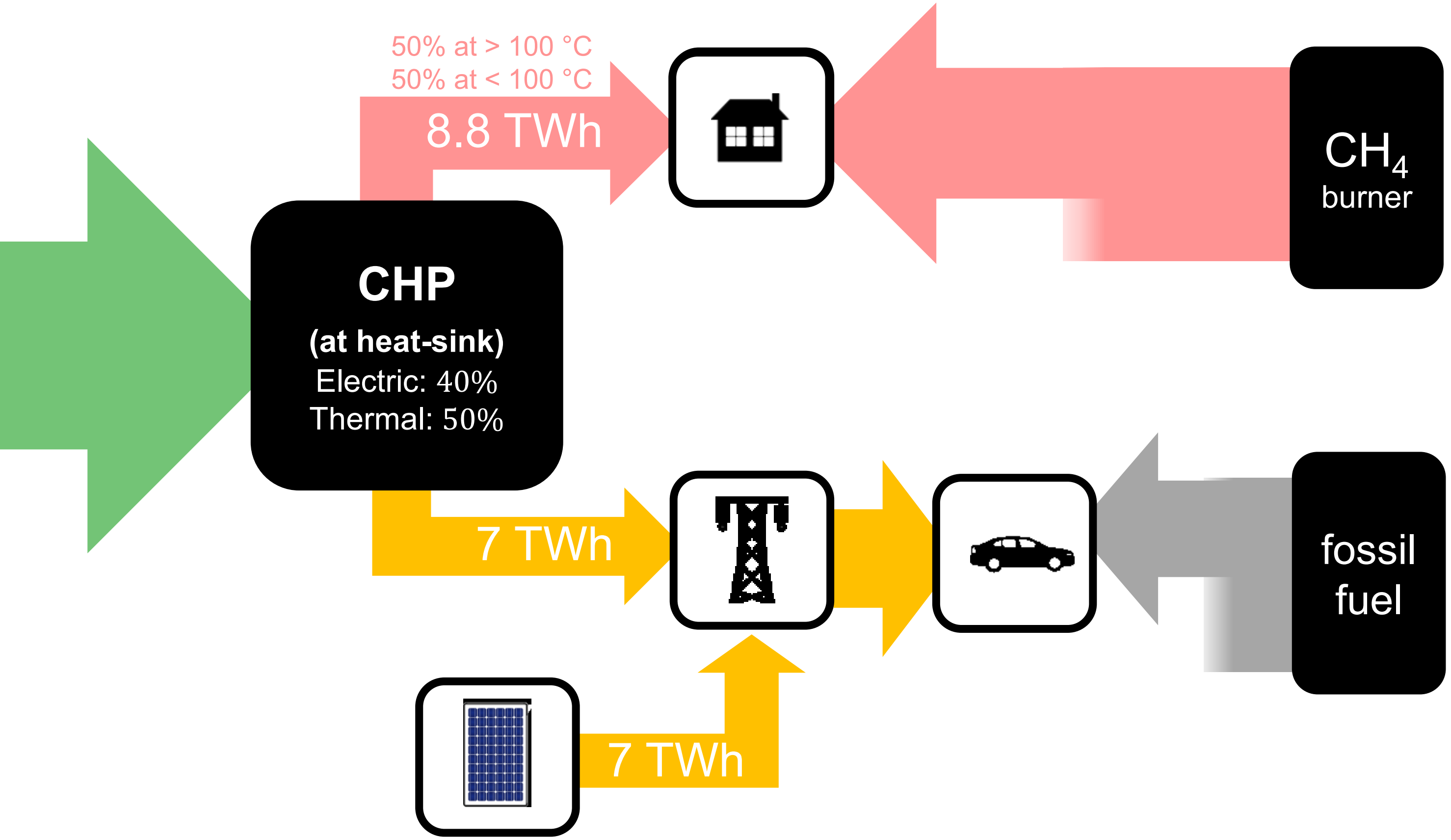
Going even further → combining a "CHPswarm" with e-mobility

→ using CHP swarm to maximally allocate fluctuating PV electricity

"CHPswarm" CHP + seasonal storage via gas-grid	**"CHP assisted PV e-mobility"** CHPswarm + PV + e-mobility
"CHP e-mobility" Electric mobility powered by continuous CHP power heat: high-temp. industrial processes	**"direct"** Biomethane as substitute fuel

Using 8000+ h/a CHP to power e-mobility

Advantage → higher CO_2 reduction due to utilization of heat



- Assuming natural gas as fuel, the demand shrinks by 8.8 TWh
- CO_2 avoidance → **1.9 Mt/a**

- Full electrification of Swiss passenger car fleet: 14 TWh/a (SCCER mobility)
- Currently emissions: 10.2 Mt/a (BAFU)
- CO_2 avoidance → **10.2 Mt/a**

$$\approx -\mathbf{12.0}\ \boldsymbol{Mt/a}$$

PV powered E-mobility, with CHPswarm filling in provision gaps

Essentially the CHPswarm concept with mobility as sole electricity load

- Assuming portfolio includes primarily seasonally dependent heat sinks
  - 7 TWh electricity production form CHPs (for e-mobility) → 3 GW @ 2300 h/a
  - 7 more TWh from PV (required, for e-mobility) → 7 GW peak power (assuming 1000 h/a)
- Seasonal imbalance of electricity production and demand

	winter	summer	ΔCO_2	explanation
Electricity from CHP	5.6 TWh	1.4 TWh	1.9 Mt	80% of heat demand in winter → 80% of production in winter; CO2 reduction from replacing fossil fuelled boilers
Electricity from PV	2.0 TWh	5.0 TWh	/	70% of PV production in summer
Demand from EVs	7.0 TWh	7.0 TWh	10.2 Mt	Assumed seasonally independent; CO2 reduction from displacing fossil-fuelled passenger cars
Net balance	**+ 0.6 TWh**	**- 0.6 TWh**	**12 Mt**	

$$\approx -12\ Mt/a$$

  - Need to transfer 0.6 TWh from summer to winter (at least → assuming no storage losses)

Parallel energy system (PV+CHP+storage) for mobility → costly

→ return to original CHPswarm concept with mobility as just one load among many

"CHPswarm" CHP + seasonal storage via gas-grid	**"CHP assisted PV e-mobility"** CHPswarm + PV + e-mobility
"CHP e-mobility" Electric mobility powered by continuous CHP power heat: high-temp. industrial processes	**"direct"** Biomethane as substitute fuel

In a nutshell: different paths and their mitigation potential

For reference (BAFU)
national: ~43 Mt CO_2/a
(incl. aviation)

	CO_2 from mobility [Mt/a]	CO_2 from heat [Mt/a]
Direct substitution of fossil fuels (in mobility)	~4.4	0
CHP for e-mobility + industrial heat (all year)	~5.1	~1.9
PV + balancing CHP for e-mobility + residential heat	~10.2	~1.9 (2.4 when substituting oil)

Caveats:
- ❑ Economic, policy and technical constraints not considered → will define effective potential
- ❑ CO_2 emissions do not include embedded emissions

Conclusions

Thermodynamically: CHP path → higher CO_2 reduction

- Among CHP options, highest potential for seasonal balancing → PV integration

Practically: additional constraints apply

- Electrification may not be an option for certain transport modes → require chemical fuel
- Flexibility may or may not be an asset in future energy systems → e.g. “supergrid”
- All year vs. seasonal concept → depends also on availability of heat sinks in future decades

In conclusion: biomass is a flexible energy vector for different scenarios

- Optimal allocation of bioenergy determined by exogenous developments
  such as : supergrid, cost of e-fuels, policy induced costs / subsidies, …