Which role for GAS in the energy transition?

Jan Van herle

Group of Energy Materials (GEM)

EPFL

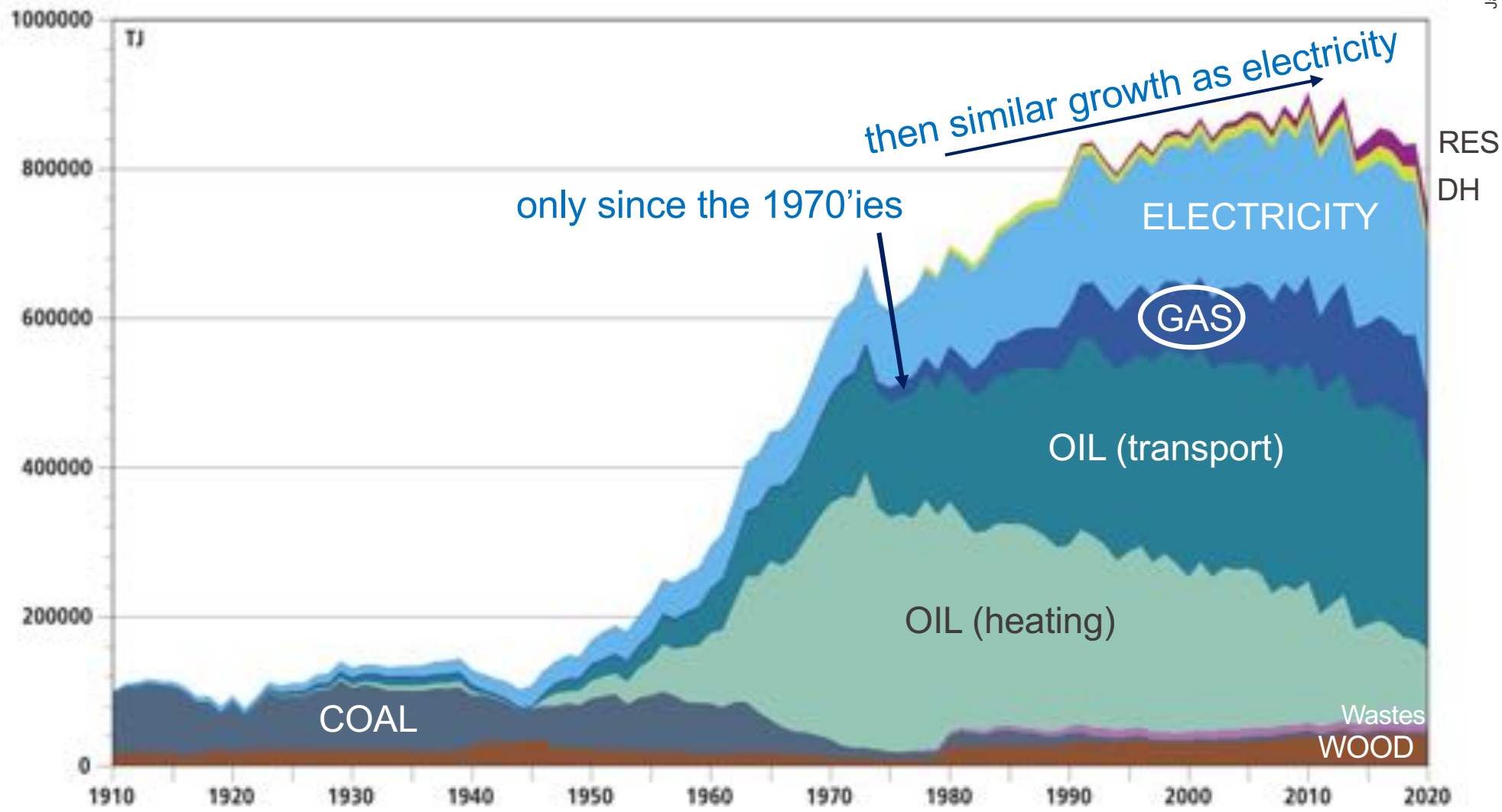
InnoClimat

Montreux

2021-Nov-04

1. Role of GAS today: Switzerland

Historically



RES: other renewable energy sources
DH : district heating

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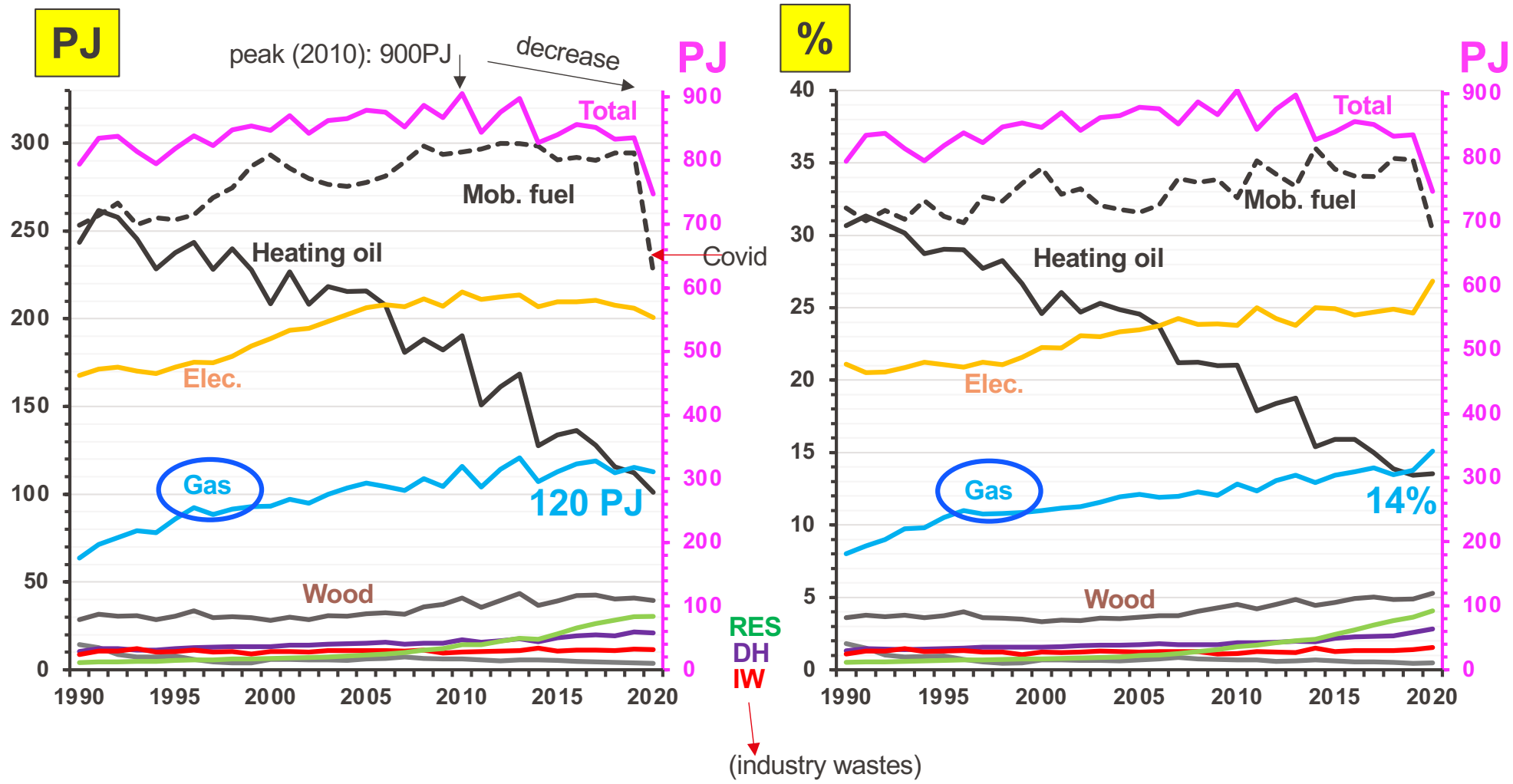
Shares in final energy by fuel



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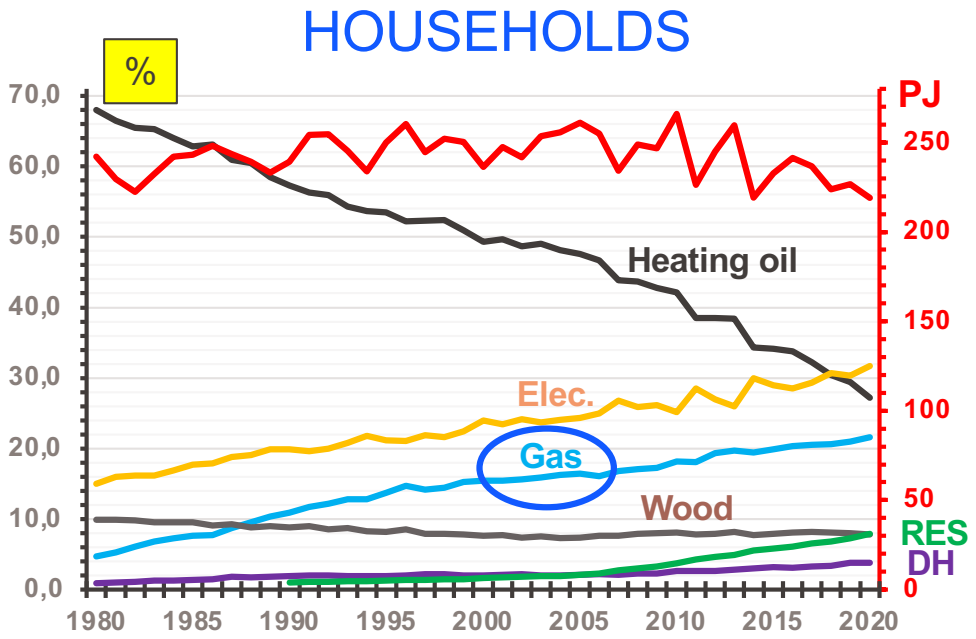
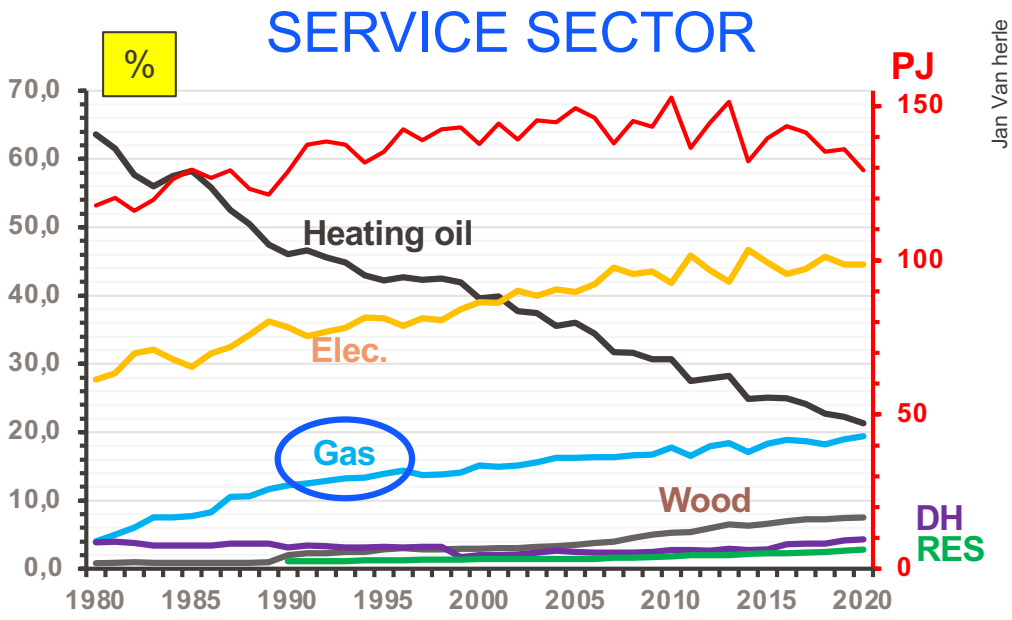
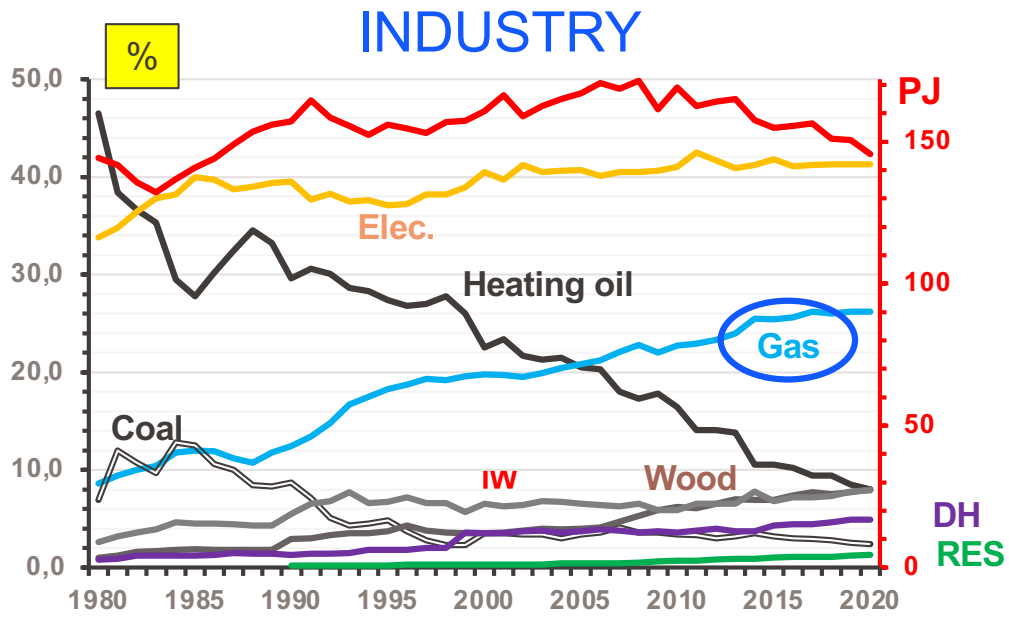
Trend per sector







- Gas & electricity replace oil
- Other renewables increase too
- Electricity ~50% in IND./ SERV.

Key figures for Gas (CH)

- 3rd energy vector (14%) after oil (50%) and electricity (25%)

- main (92%) use is for heating in the 3 sectors:
  - 39% of gas => Households (gas = 24% of all HH energy)
  - 32% of gas => **Industry** (gas = 32% of all IND.) – esp. for process heat
  - 21% of gas => Services (gas = 22% of all SERV. energy)
- minor (7%) use in combined heat & power (**CHP**) production for district heating, and in *engines* smaller than 1 MWe
- marginal (0.2%) use in mobility

- low loss in **gas grid** distribution (0.8%) ✅ (⇔ electrical grid: -7%)

- biogas inland production now is <5% of imported natural gas
  - main part (75%) is converted in small **CHP** (~200kWe *engines*), **70 MWe** total, to deliver 0.6% of Swiss electricity
  - ~remainder is injected as biomethane to the gas grid (=**1%** of total gas)

GAS flows in GW-equivalent

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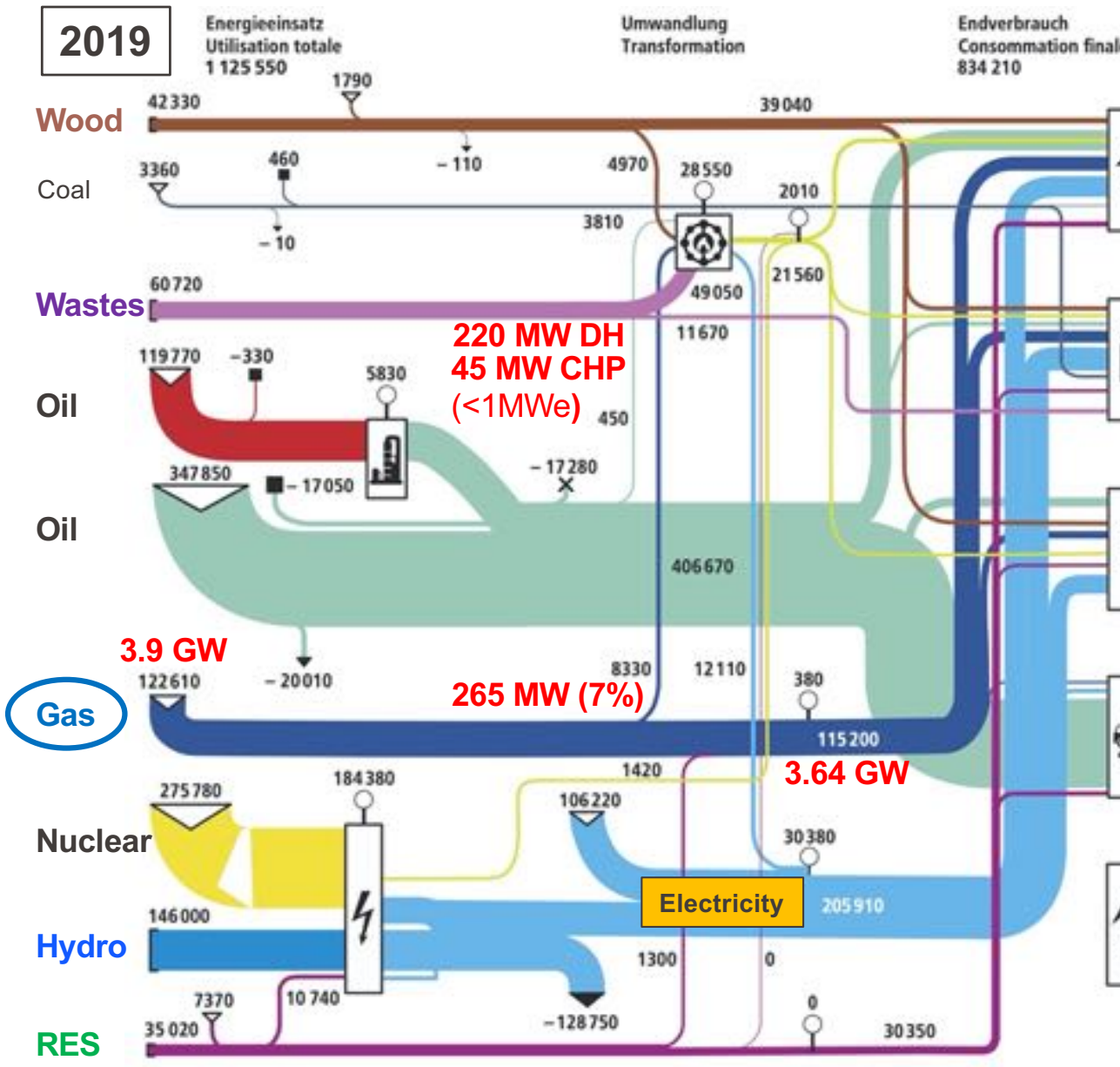


3085 W/person

838 W/person

1.5 GW (39%)

8.575 mio people

Households

Gas:24%

77 kW/site

1.25 GW (32%)

62'000 sites

Industry

Gas:32%

8-24 kW/site

0.82 GW (21%)

299'000 sites

Services

Gas:22%

19 MW for transport

Mobility

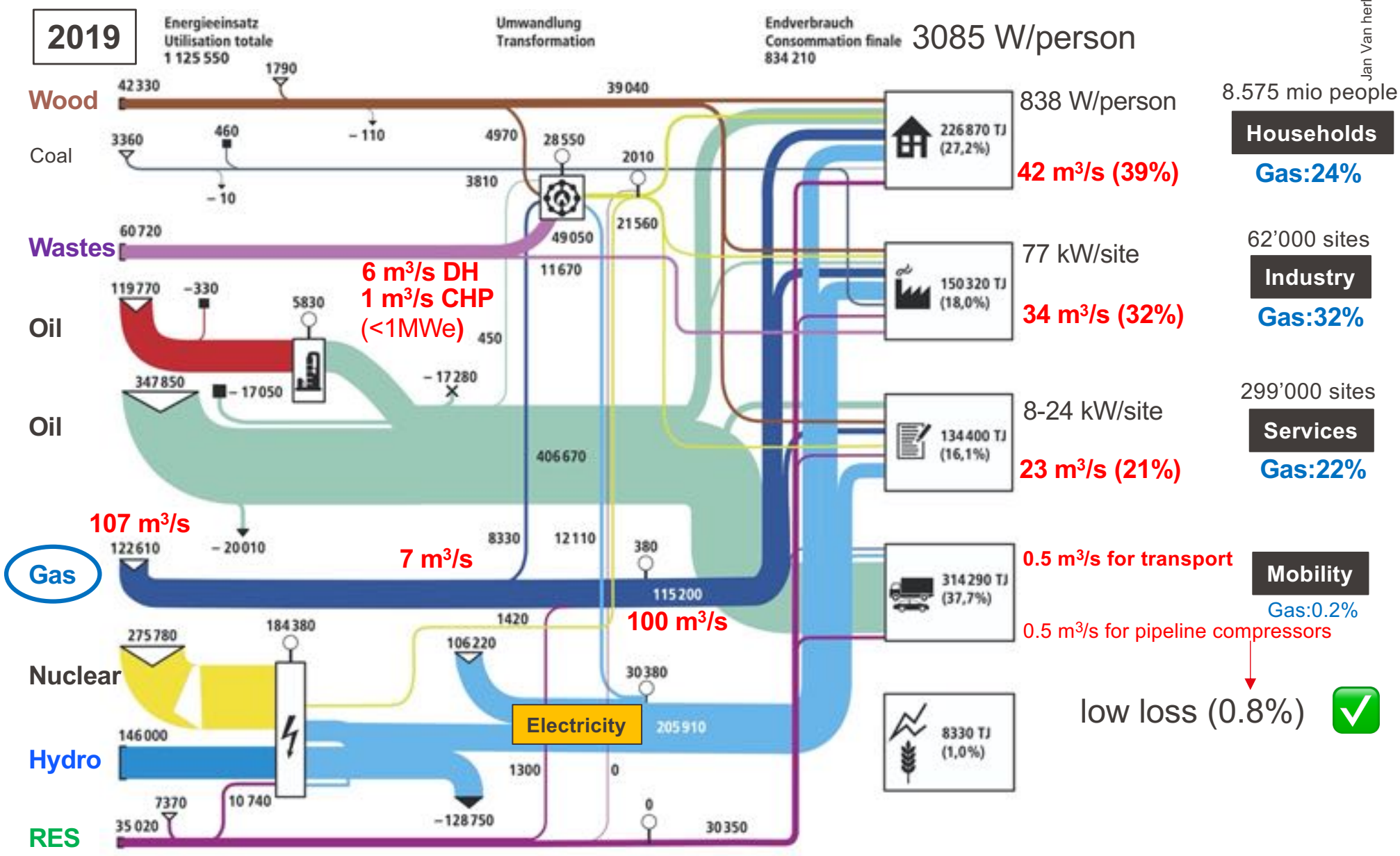
Gas:0.2%

19 MW for pipeline compressors

low loss (0.8%) ✅

(adapted from Swiss Federal Energy Office Energy Statistics 2019)

GAS flows in m^3/s - equivalent



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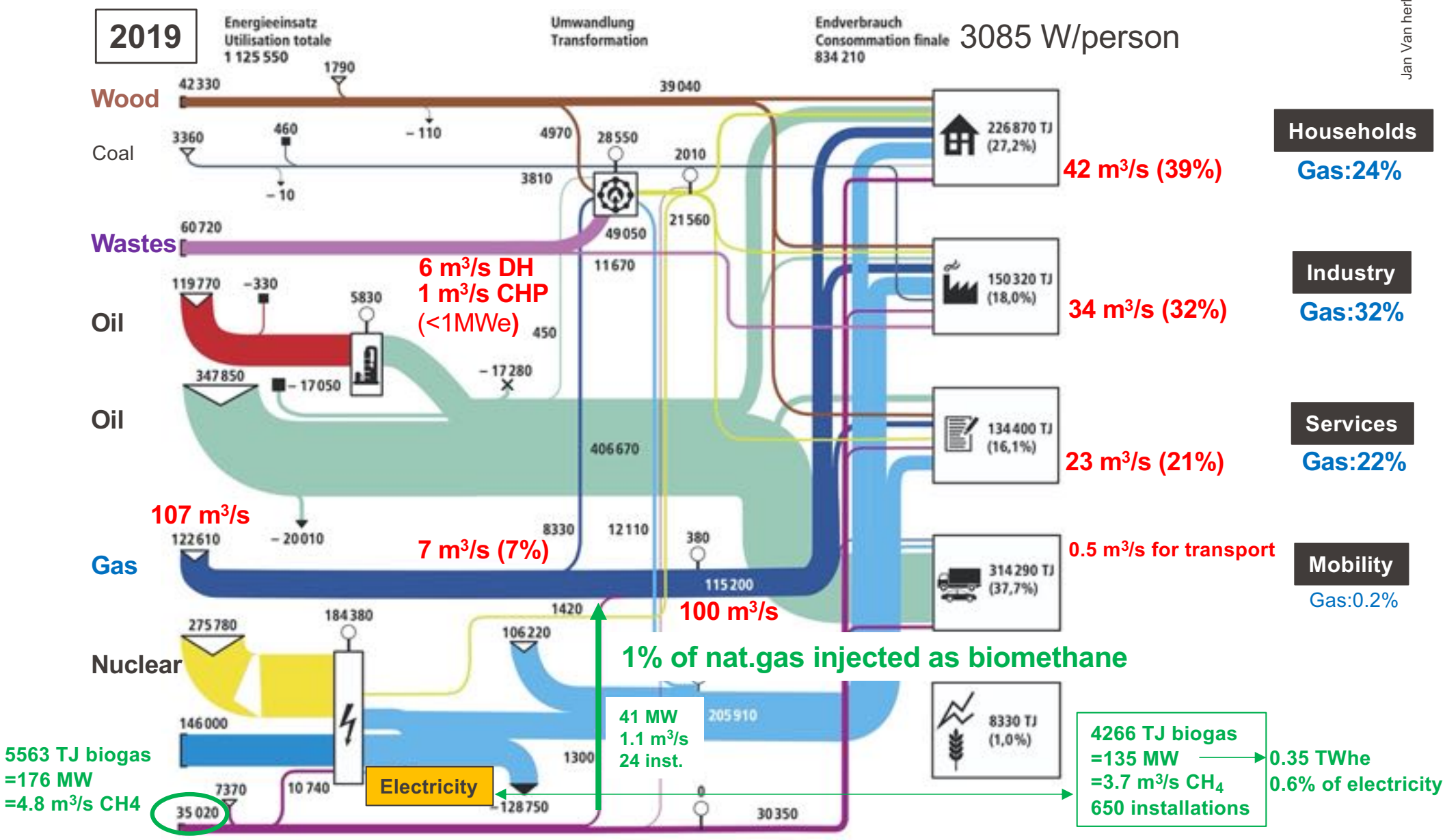
Contribution from BIOGAS



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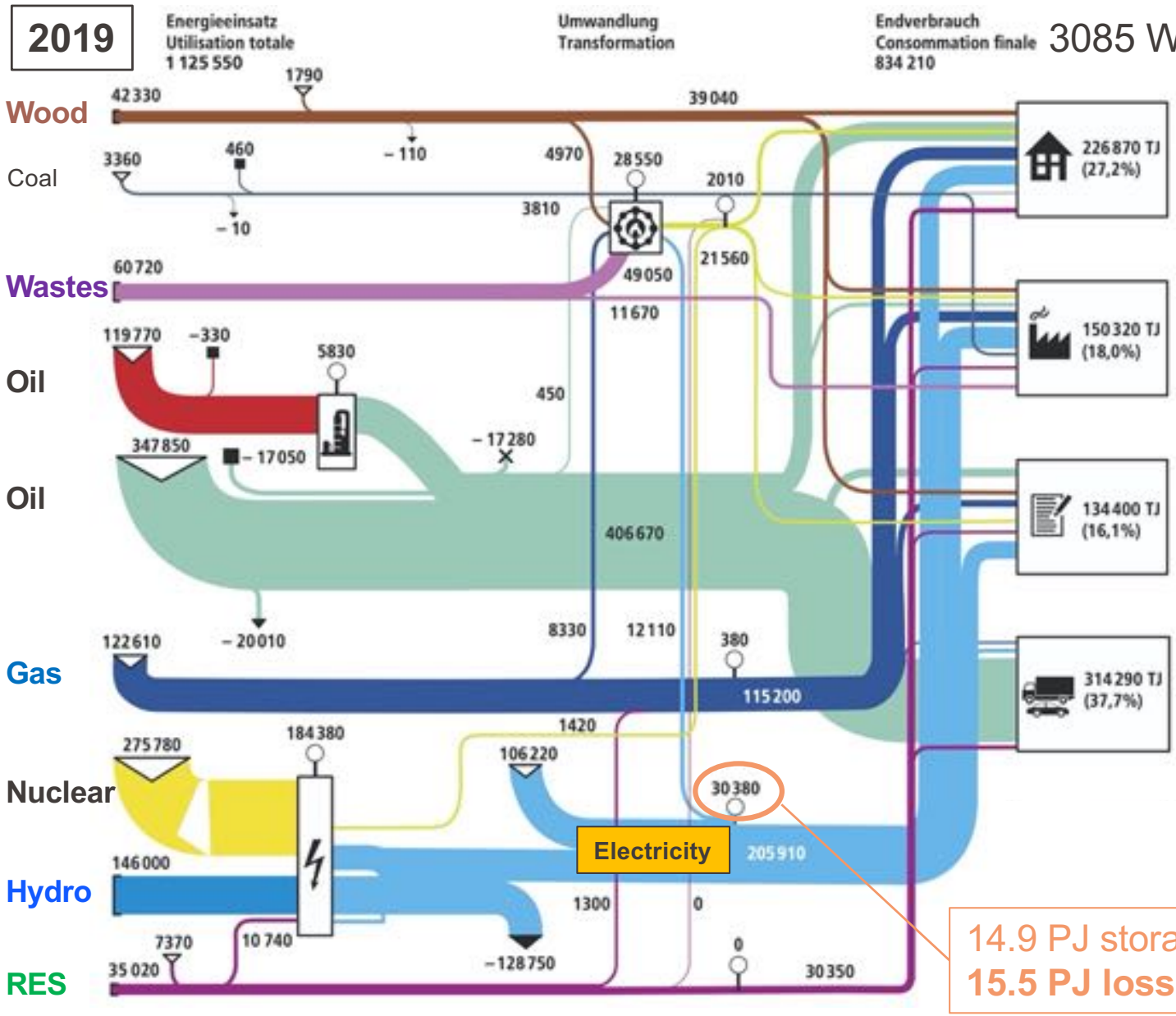
Distribution loss: gas vs. electricity



3085 W/person

Households
Gas:24%

Industry
Gas:32%

Services
Gas:22%

Mobility
Gas:0.2%

0.5 m³/s for transport

0.5 m³/s for pipeline compressors

gas: low loss (0.8%) ✅

14.9 PJ storage (4.1 TWhe)
15.5 PJ loss = - 4.3 TWhe (7% !)

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Gas: important for high temperature heat (industry)

PJ	Households	Service sector	Industry
Space heat + HW	180.7	71,3	16,6
Oil	68,0	28,4	3,7
Gas	45.1	22,7	5,7
Electricity	23,7	4,6	
Wood	17,9	7,0	3,3
DH	9,7	4,8	1,7
RES	16,1	3,8	0,6
Other			1,3
Process heat	5,5	2,8	88,3
Oil			4,0
Gas	0,3		32,7
Electricity	5,1	2,8	21,6
Wood			7,3
Coal			5,1
DH			4,3
Other			12,7
Cold (electricity)	0.4	13,4	3,4
Total Final Energy	186,6	87.5	108.3

Industry	PJ	%
Temperature	**88,3**	**100%**
<100°C	15,9	18%
100-200°C	12,0	14%
200-400°C	5,8	7%
400-800°C	32,0	36%
800-1200°C	16,0	18%
>1200°C	6,6	7%

>60% high T heat

difficult to replace by other sources

Source: Analyse des schweizerischen Energieverbrauchs 2000–2019 nach Verwendungszwecken, October 2020

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Electricity ↗ 50% in Industry/Services - demand often 10 – 100 kWe per site

				Heating fuel %						Elec.%		
		GAS cons	Share	GAS	Oil	Coal	IW	DH	Wood		kWe/site	Sites
	INDUSTRY SECTOR	36,3	100	30	8	4	9	4	4	43	27	62102
1	**Chemie/Pharma**	11,7	32	44			16			33	337	839
2	**Food**	7,5	21	44	10					46	61	4086
3	**Ferrous metal**	3,3	9	42		5				52	1189	112
4	**Metal devices**	2,9	8	20	14					65	37	8201
5	**Paper/Impression**	2,2	6	21			3	22	7	48	94	1754
6	**Cement/concrete**	1,8	5	13		27	41		7	12	1268	41
7	**Other minerals**	1,7	5	43	8	7				42	53	963
8	**Other industries**	1,4	4	12	11				19	57	26	8726
9	**Non-ferrous metal**	1,4	4	49						48	395	109
10	**Machines**	1,0	3	19	20			2		60	51	1864
11	**Building construction**	0,7	2	18	43					39	1,4	34148
12	**Textiles**	0,6	2	43	20					37	14	1259
		PJ	%	36	9,7	4,5	11,0	5,0	4,4	%	kWe	

				Heating fuel %						Elec.%		
		GAS cons	Share	GAS	Oil	Coal	IW	DH	Wood		kWe/site	Sites
	SERVICE SECTOR	25,1	100	22	20	0	0	4	1	53	6,4	298861
1	**All other services**	7,6	30	23	16			4	1	57	5	126337
2	**Hospitals/EMS/Health**	5,1	20	31	17			8	2	43	6	36262
3	**Schools**	4,1	16	33	23			5	1	40	9	17718
4	**Trade**	3,3	13	13	23					63	7	69932
5	**Hotels/restaurants**	2,2	9	15	27					57	10	26030
6	**Administration**	2,1	8	31	17			7	2	42	10	8699
7	**Banks/insurances**	0,9	4	20	15			5		60	7	13883
		PJ	%	25	22			4	1	%	kWe	

(adapted from: Energieverbrauch in der Industrie und im Dienstsektor, July 2018)

Gas = main heating fuel in the service and esp. industry sector

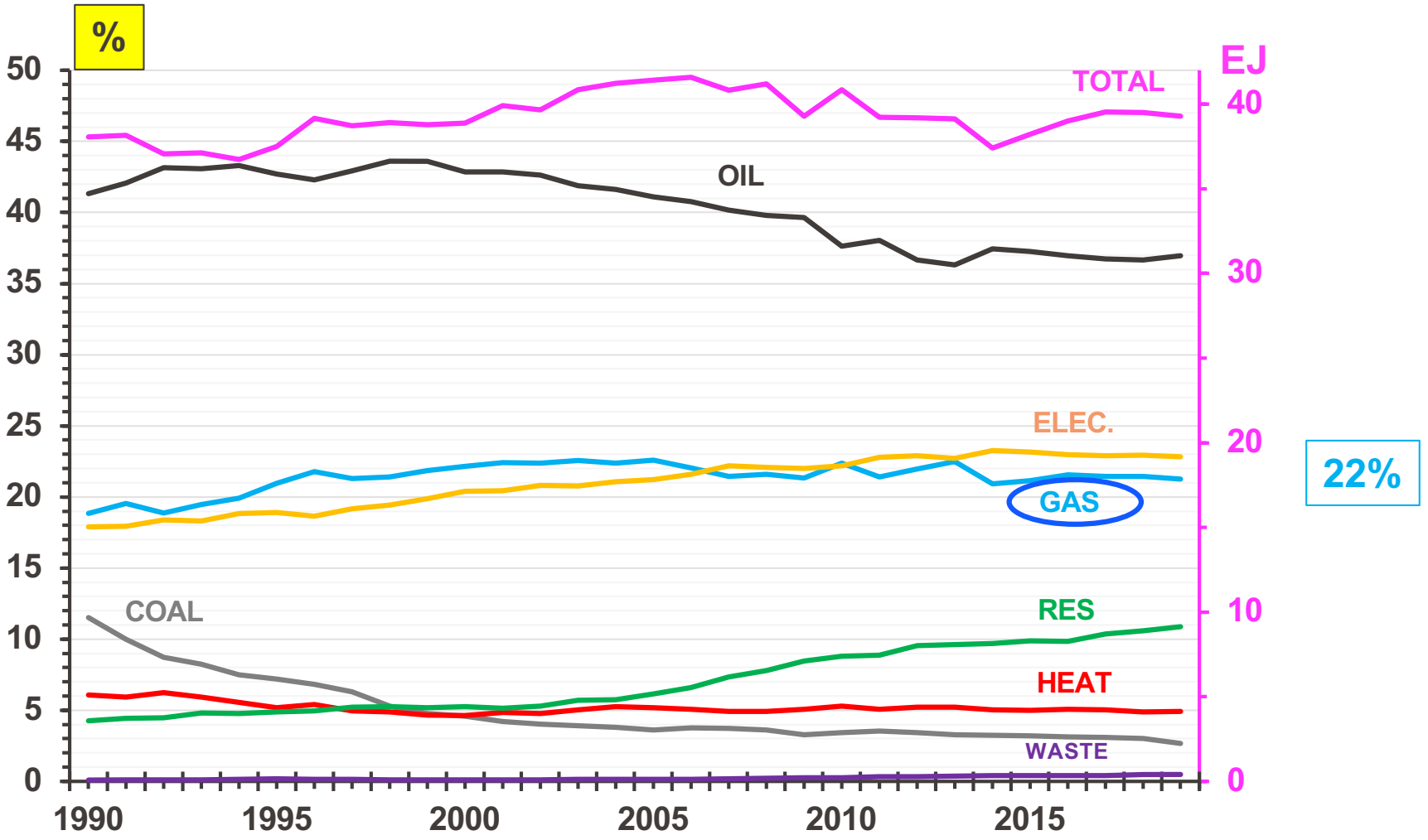
Elec. demand = often 50% and even 60%

Power size = ~10 kWe in service sector and mostly <100 kWe in industry sector

Efficient gas-based CHP is interesting

2. Role of GAS today: Europe

Shares (%) in final energy by fuel (EU-27)



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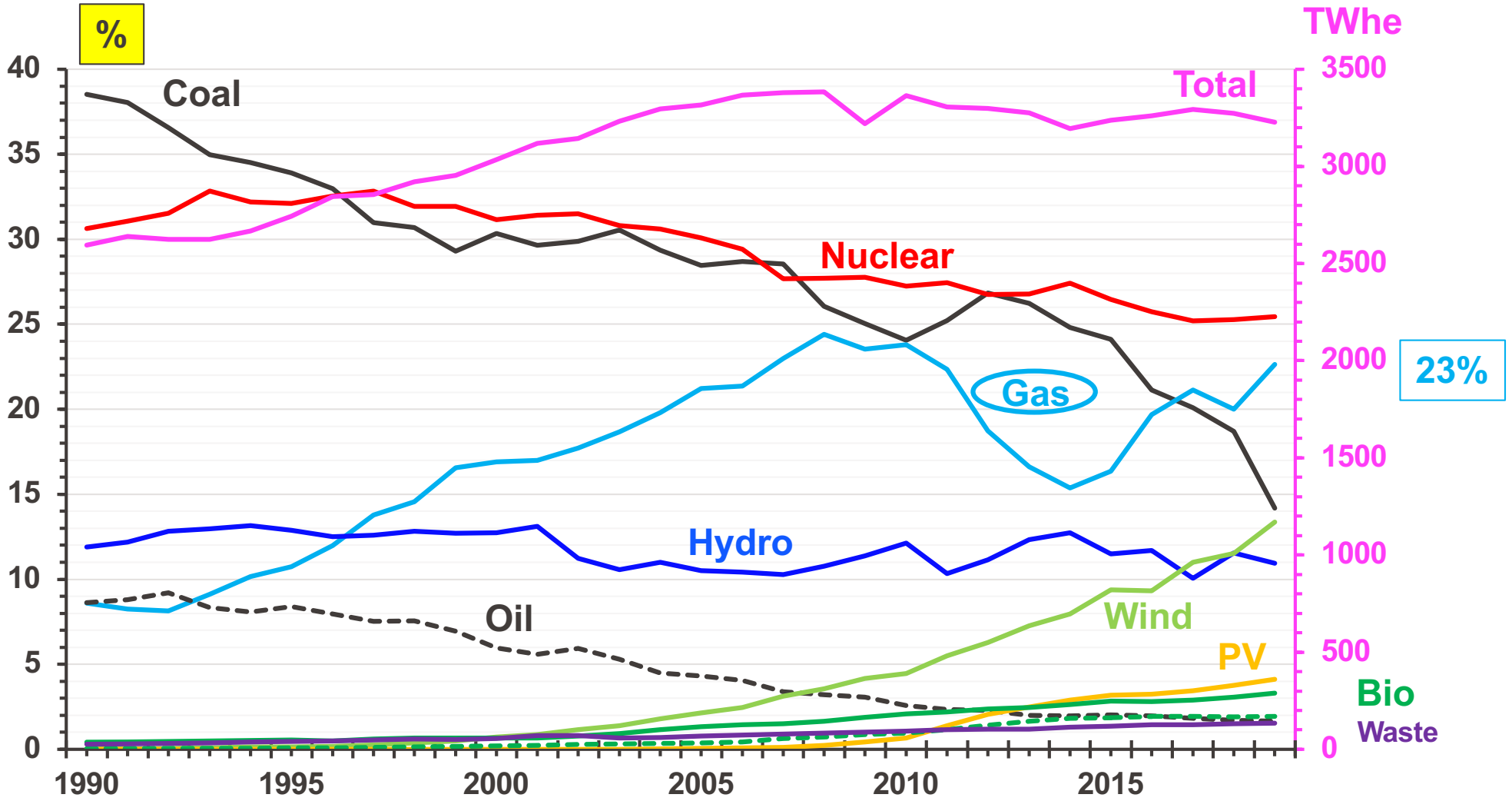
Shares (%) in electricity production (EU-28)



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Key figures for GAS in EU

- 3rd energy vector (22%) after oil (37%), same level as electricity (23%)

- main (72%) use for heating in the 3 sectors:
  - 29% of gas => Households (gas = 32% of all HH energy)
  - 30% of gas => **Industry** (gas = 34% of all IND.) – esp. for process heat
  - 13% of gas => Services (gas = 32% of all SERV. energy)
- important use (26%) for electricity production (=> 23% of EU-electricity)
- little use in mobility (1.5%)

- low loss in gas grid distribution (<0.8%) ✅ (⇔ electrical grid: -7%)

- biogas inland production now is <5% of imported natural gas
  - main part (92%) is converted in **CHP** (~500kWe *engines*), total **11 GWe**, to deliver 2% of EU electricity (**62.5 TWhe**)
  - remainder 8% is injected as biomethane to the gas grid (=0.5% of NG)

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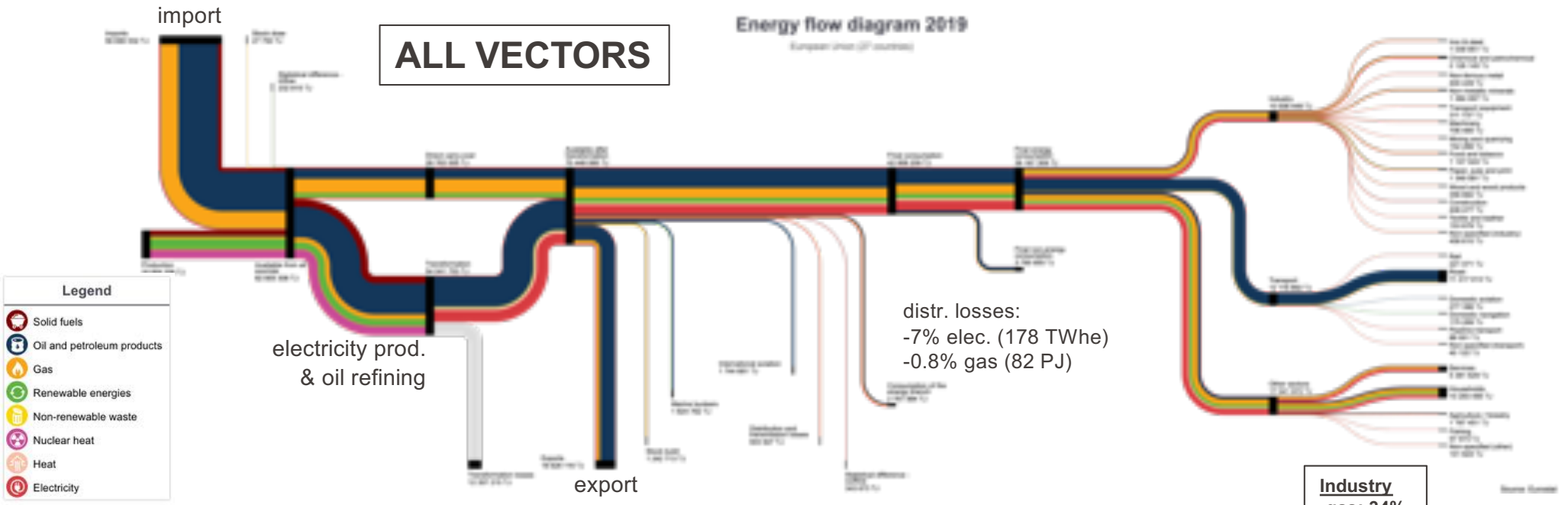
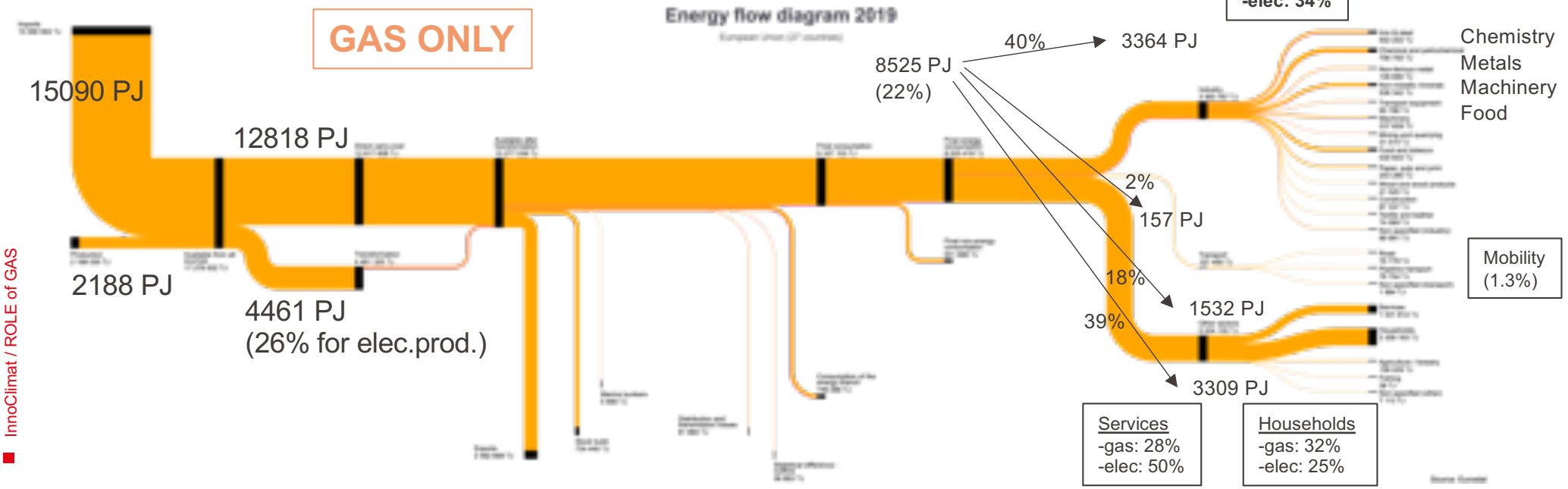
ALL VECTORS



GAS ONLY



3. Innovation R&D around 'GAS'

Building sector

Source: EUROPE'S BUILDINGS UNDER THE MICROSCOPE
A country-by-country review of the energy performance of buildings
2011, Buildings Performance Institute Europe (BPIE)

Figure 1C3 – Historical final energy use in the residential sector in EU27, Norway and Switzerland

Source: Eurostat database

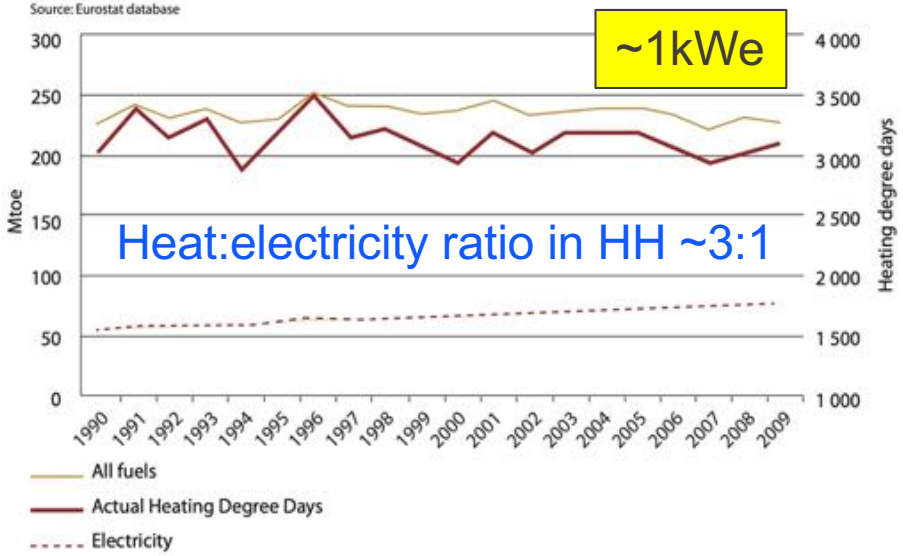


Figure 1C9 – Historical final energy use in the non-residential sector in the EU27, Norway and Switzerland

Source: Eurostat database

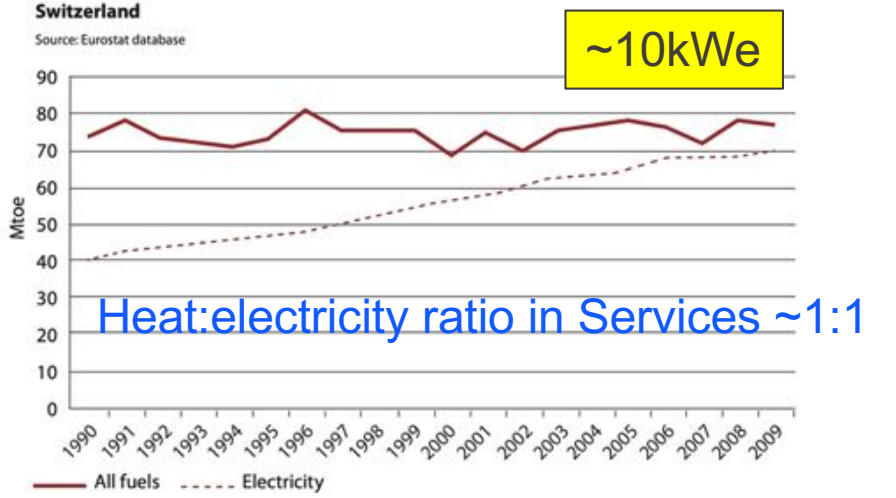
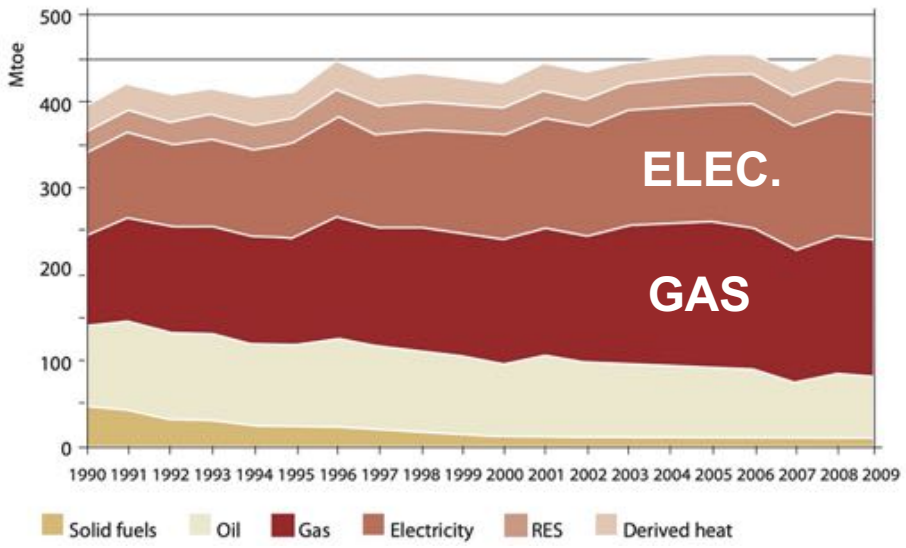


Figure 1C1– Historical final energy consumption in the building sector since 1990s for the EU27, Switzerland and Norway

Source: Eurostat database



A clean gas-based decentralised CHP (combined heat & power) technology with high electrical efficiency for use in buildings could be interesting

=> **Fuel cells**

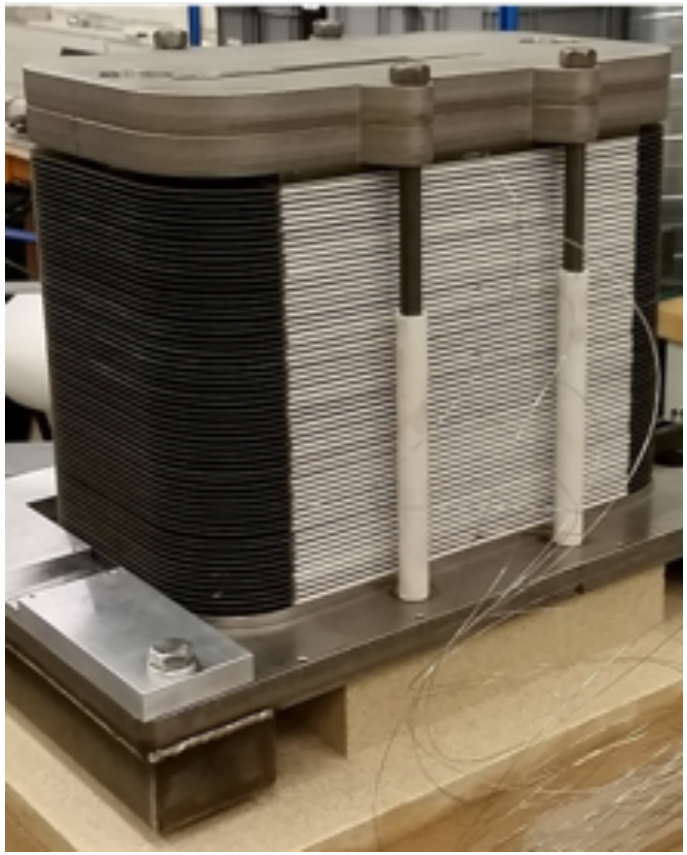
Fuel cell cogenerator

1.5 kWe stack

no:

~~CO~~
~~HC~~
~~NOx~~

New upscaled unit : 6 – 8 kWe



CO_2, H_2O

Certified output:

63% el.eff.

26% therm. (hot water)

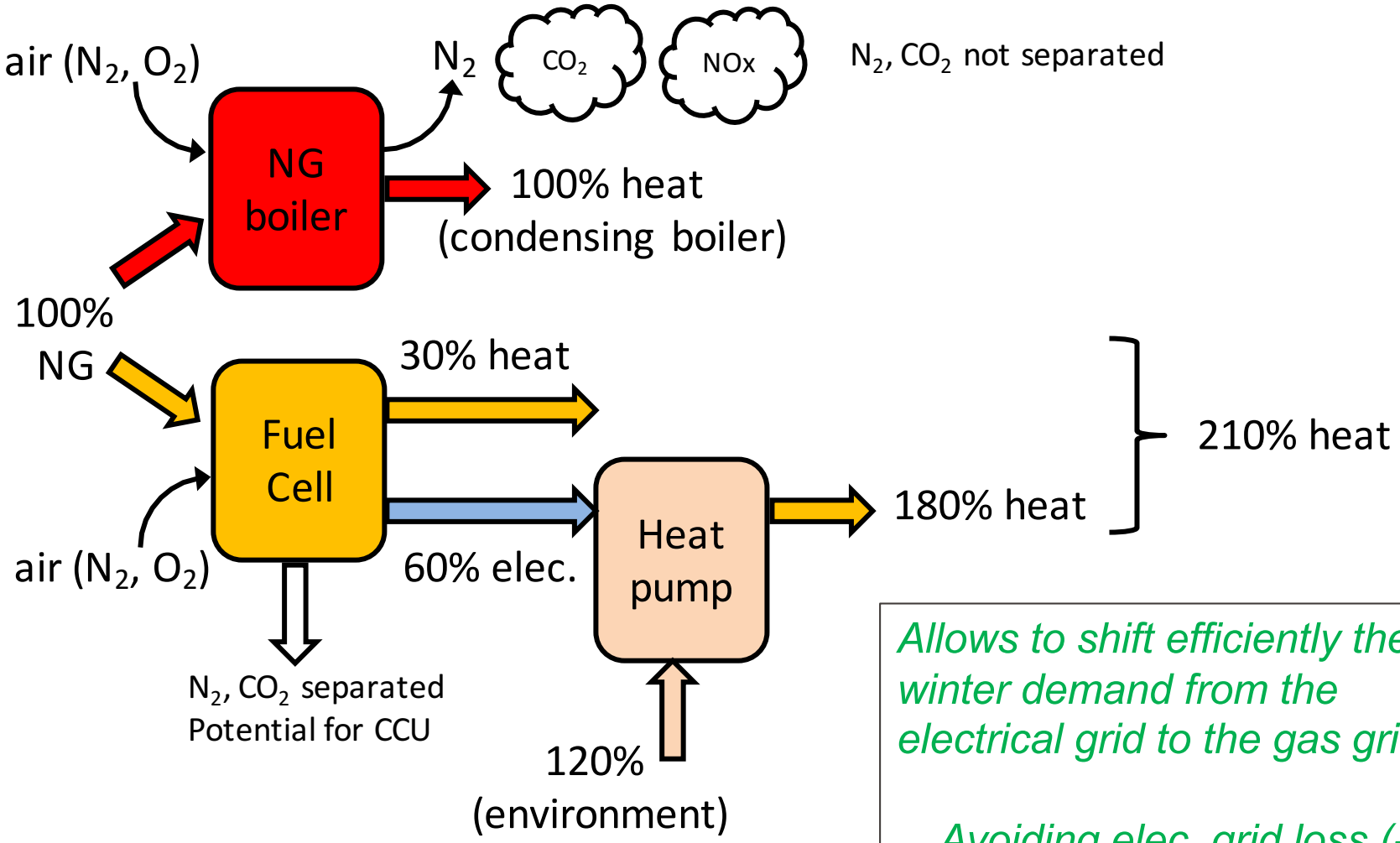
NG from grid

for HOUSEHOLDS

for SERVICE SECTOR

For residential case : fuel cell + heat pump

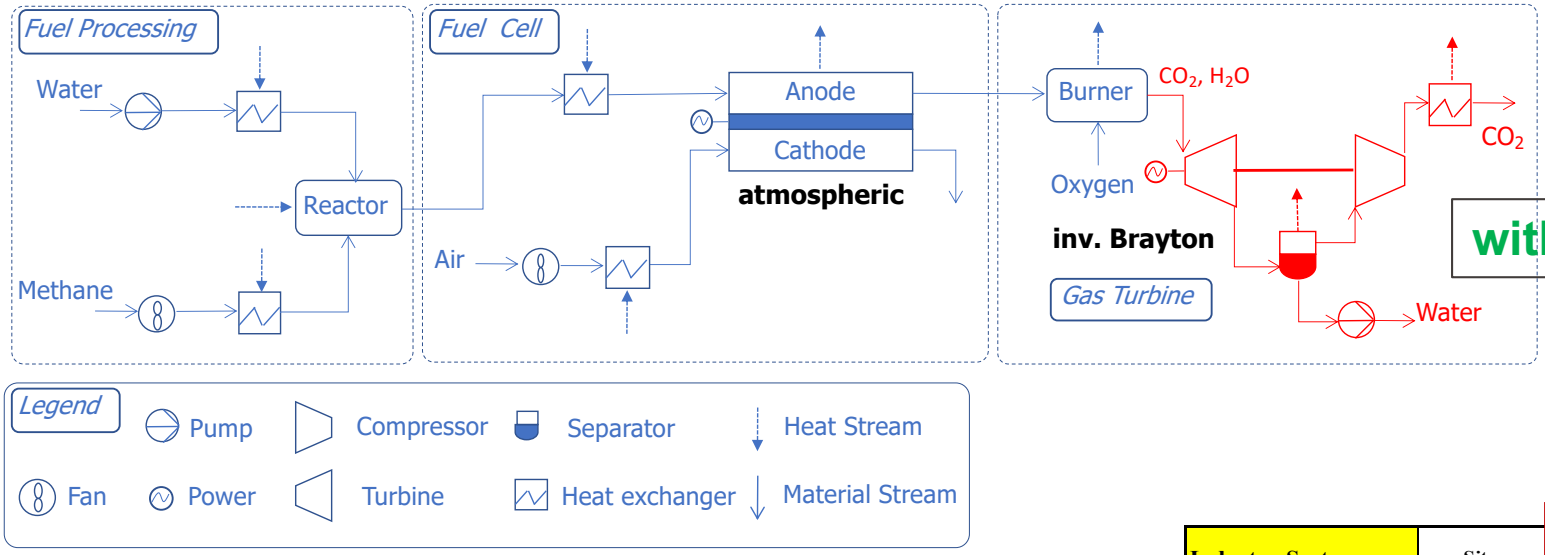
(heat/electricity need ≈ 3/1)



Allows to shift efficiently the winter demand from the electrical grid to the gas grid.

…Avoiding elec. grid loss (-7%), and recovering the heat.

For highest elec. efficiency (>65%): fuel cell – microturbine hybrid (10-100 kWe scale)



gaz nat

with CO_2 separation

Industry Sector	Sites	Avg. power (kWe)	Elec-Heat ratio	Gas share in heat supply
Food	4086	**61**	44 : 56	75%
Textiles	1259	**14**	37 : 63	67%
Paper/ Printing	1754	**94**	45 : 55	35%
Minerals (except cement)	963	**53**	42 : 58	74%
Metal devices	8201	**37**	64 : 36	56%
Machines	1864	**51**	57 : 43	43%
Other' industries	8726	**26**	57 : 43	27%
Service Sector				
Trade	69932	**7**	63 : 37	36%
Hotels/restaurants	26030	**10**	57 : 43	34%
Banks/insurances	13883	**7**	60 : 40	49%
Administration	8699	**10**	42 : 58	54%
Schools	17718	**9**	39 : 61	53%
Hospitals/EMS/health	36262	**6**	43 : 57	54%
All other services	126337	**5**	57 : 43	53%

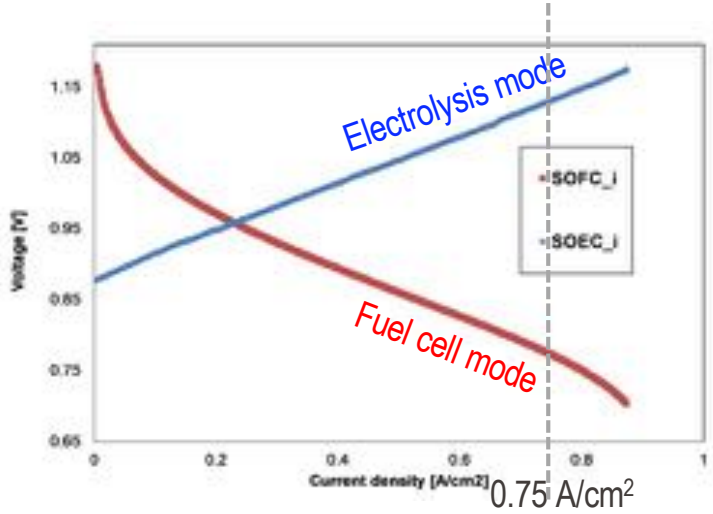
(adapted from: Energieverbrauch in der Industrie und im Dienstsektor, July 2018)

- **Prof. J. Schiffmann**

Laboratory for Applied Mechanical Design
Department of Mechanical Engineering

The fuel cell is fully reversible: => Electrolyzer

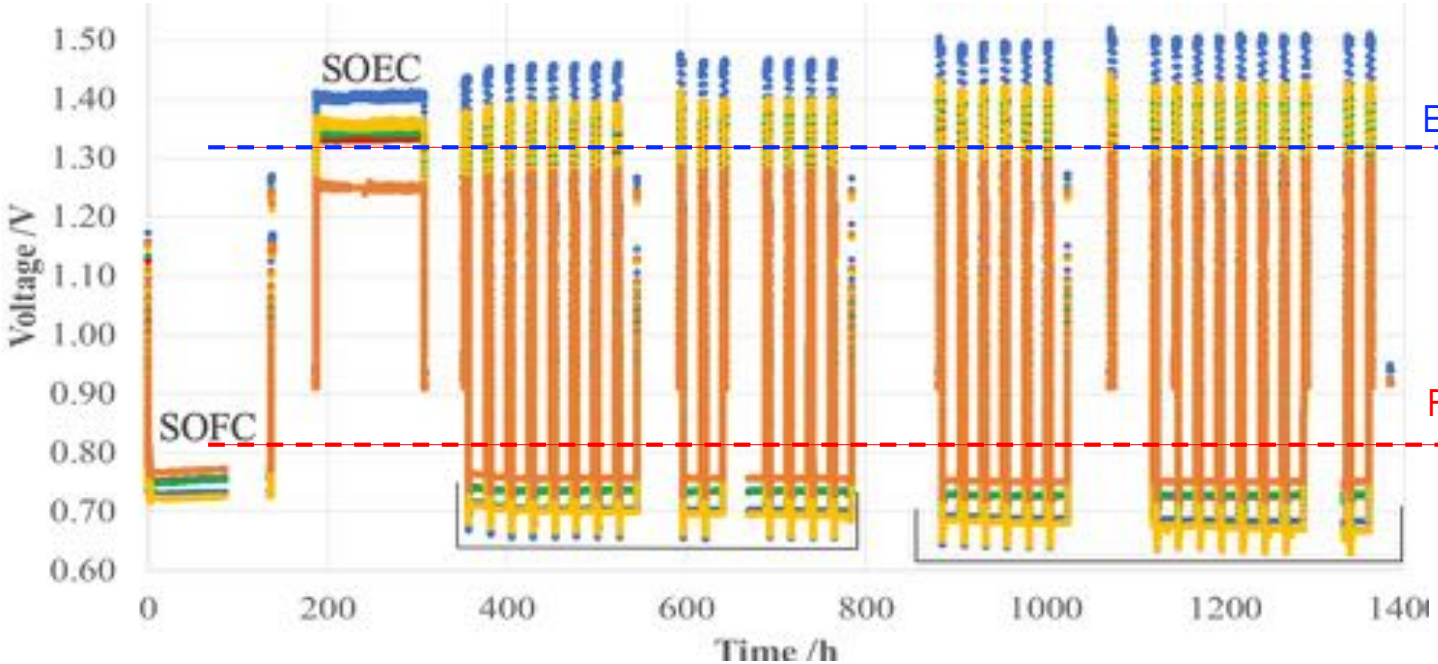
=> Power-to-Gas



0.75 A/cm²

Fuel production from electricity (=storage)

Electricity production from fuel (CH_4, H_2,…)



Electrolysis mode

Fuel cell mode

Electrolysis: 100% gross efficiency

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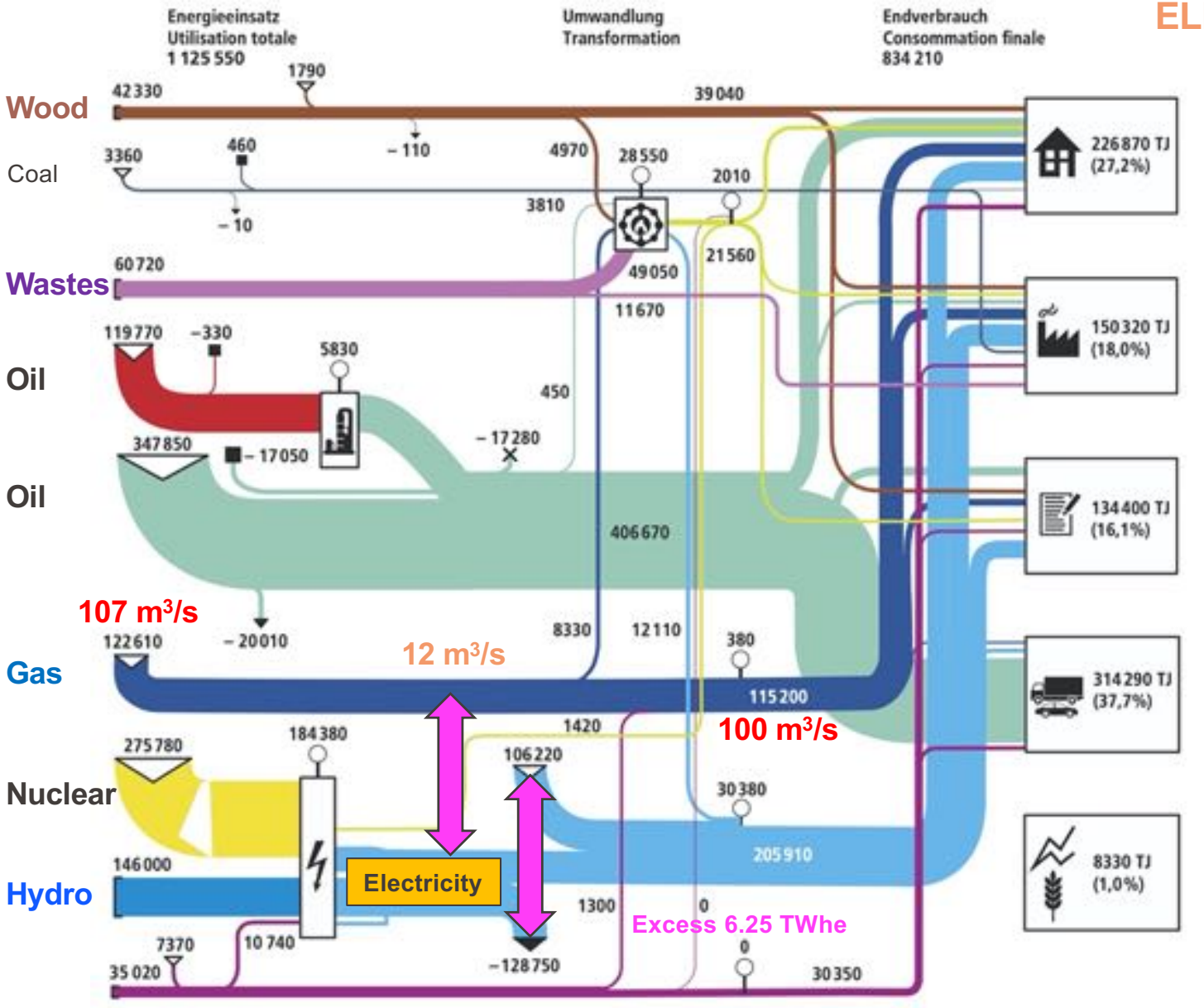
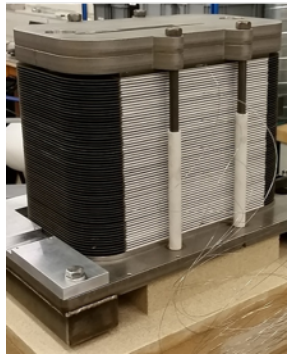
SECTOR COUPLING btw. GAS & ELECTRICAL GRIDS





Power-to-Gas:

1 TWhe
= 0.8 TWh CH_4
= 2 m^3/s CH_4

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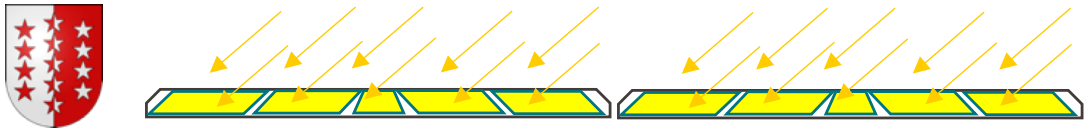
CH_4–to–CO_2–to–CH_4 with *reversible* solid oxide cell technology (*r*SOC)

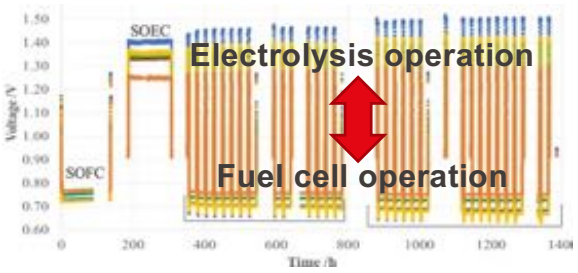


HES-SO Valais-Wallis
Cantonal Energy Demonstrator (VS)

Operation as electrolyser: $H_2O \rightarrow H_2 + ½\ O_2$
regeneration of CH_4

Fuel cell : $CH_4 \rightarrow CO_2$ + 60% ⚡ + 30% ♨

Electrolyser : CO_2 + ♨ + ⚡ (PV) → CH_4



PV-electricity

700°C

Methanator

$4H_2 + CO_2 \rightarrow 2H_2O + CH_4$

H_2

200°C

CH_4

air (O_2)

O_2

N_2

steam

H_2O

CO_2

H_2O

Operation as fuel cell:
conversion of CH_4

$CH_4 + O_2(air) \rightarrow 2H_2O + CO_2$

CO_2 recovery

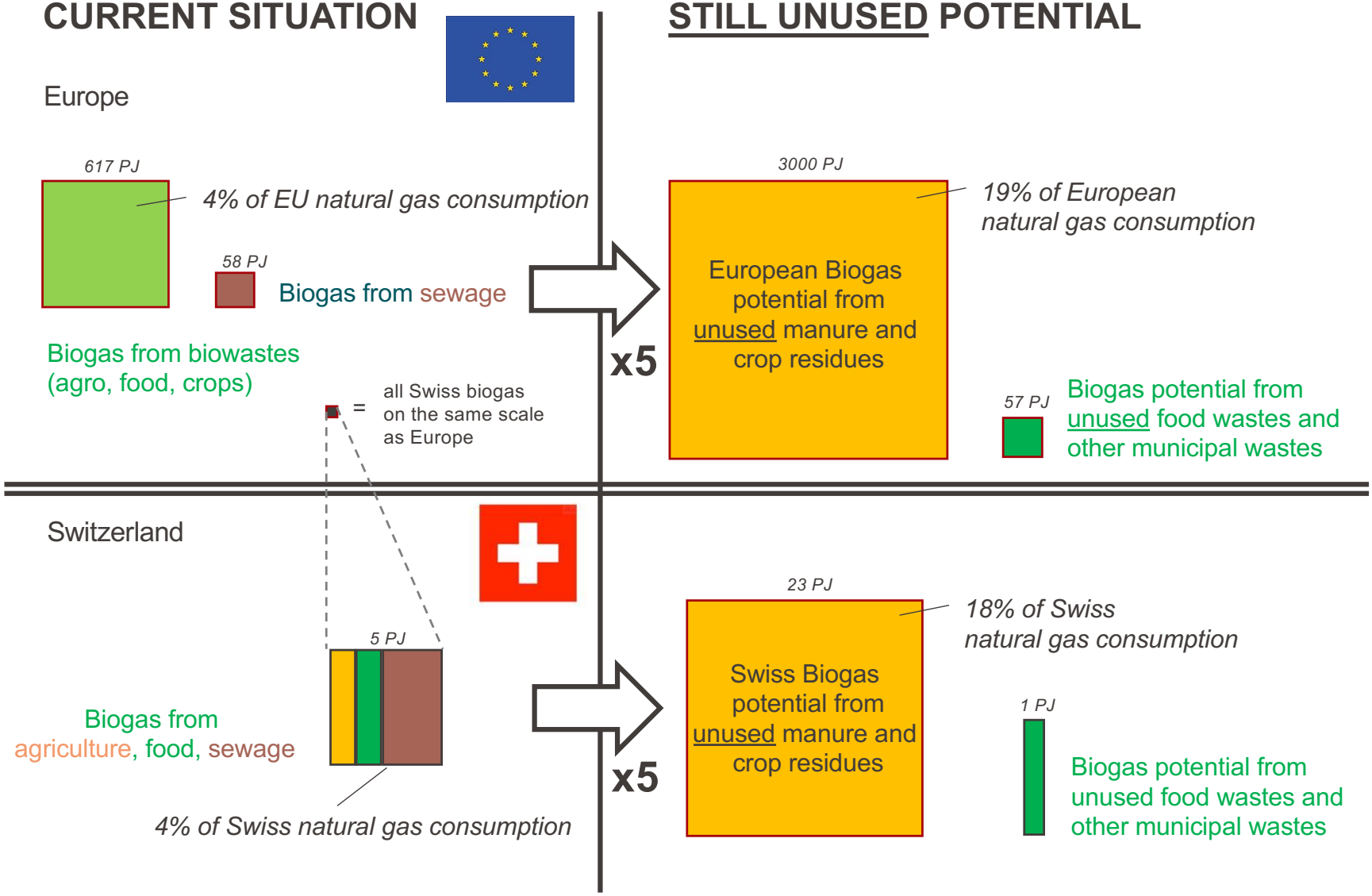
Gas grid CH_4

Gas grid CH_4

CH_4 and CO_2 circulate in closed loops without any emissions.

'greening the gas grid'

4. Biogas / Biomethane


CURRENT SITUATION
STILL UNUSED POTENTIAL
Europe
617 PJ
4% of EU natural gas consumption
58 PJ
Biogas from sewage
Biogas from biowastes
(agro, food, crops)
x5
3000 PJ
19% of European
natural gas consumption
European Biogas
potential from
unused manure and
crop residues
57 PJ
Biogas potential from
unused food wastes and
other municipal wastes
=
all Swiss biogas
on the same scale
as Europe
Switzerland
5 PJ
Biogas from
agriculture, food, sewage
4% of Swiss natural gas consumption
x5
23 PJ
18% of Swiss
natural gas consumption
Swiss Biogas
potential from
unused manure and
crop residues
1 PJ
Biogas potential from
unused food wastes and
other municipal wastes

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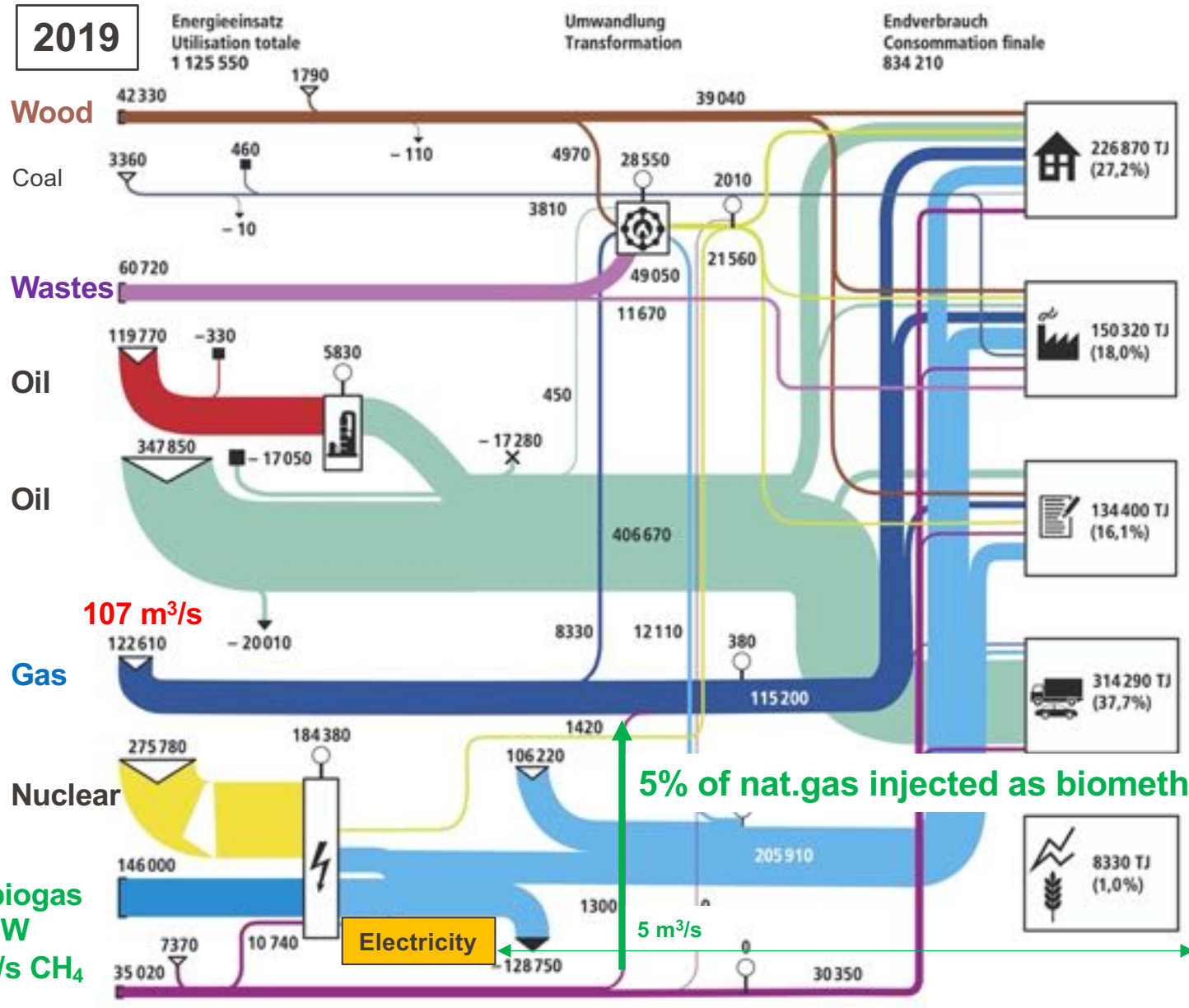
Multiply Swiss (and EU) biomethane production by x5



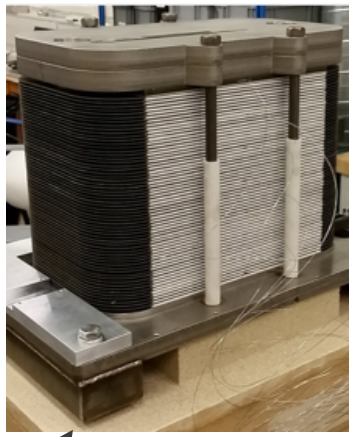
5% of nat.gas injected as biomethane

30 PJ biogas
=950 MW
=26 m³/s CH_4

24 PJ biogas
= 300 MWe
~5000 install.

→ 2 TWhe
3% of electricity

Fuel cells run
on biogas too



Biomethane / CNG for mobility

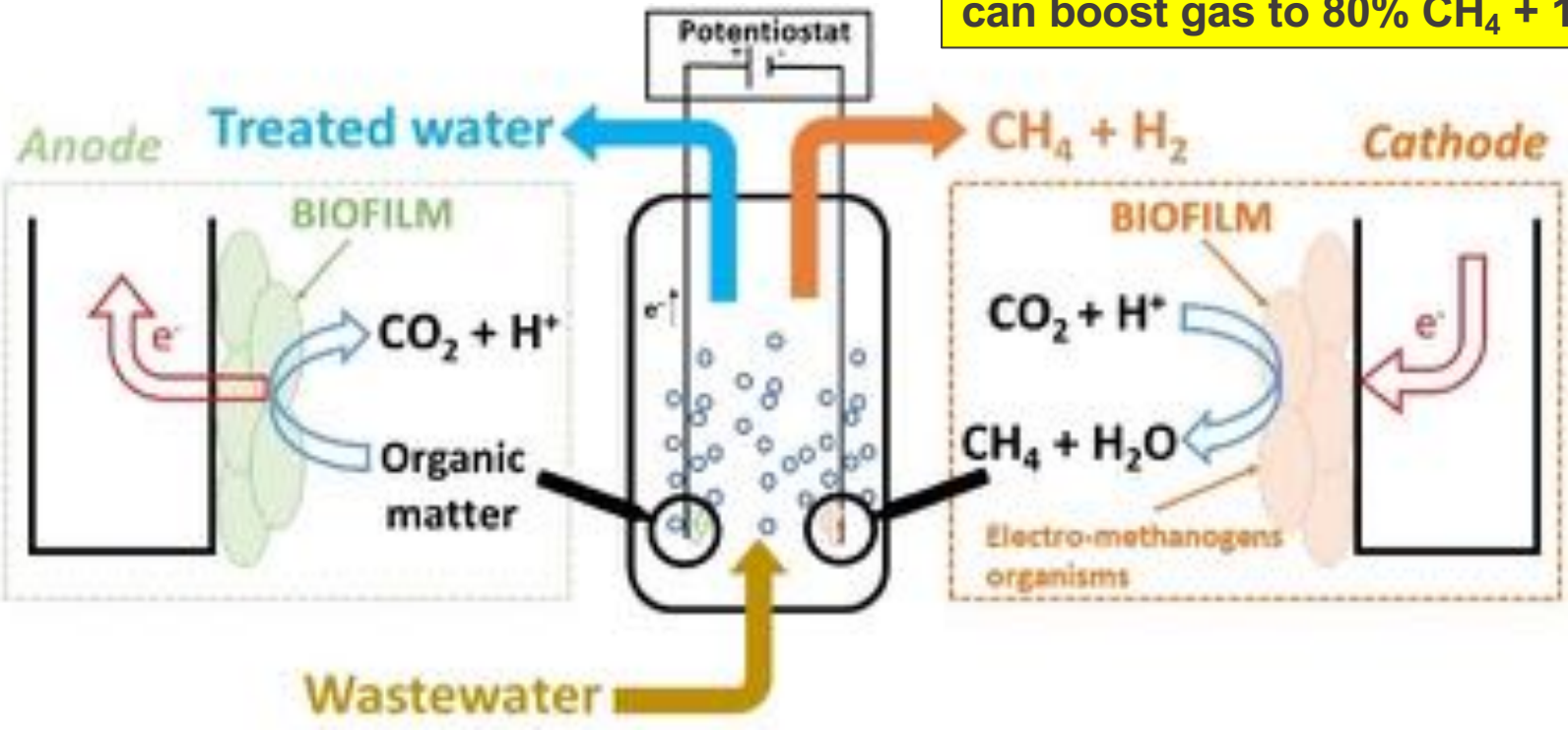
Source: Arthur Wellinger, Triple E&M

- 1.4 mio vehicles in Europe on CH_4 (worldwide: 29 mio CNG vehicles)
- 3730 CNG filling stations in Europe
- ½ the cost of gasoline
- especially suitable for large vehicles (buses, trucks, marine)
- at present >500 plants in Europe (and 25 in Switzerland) inject biomethane into the gas grid, typically at large flows (multiple 100 m^3/h per plant), related to economy of scale for the CH_4-CO_2 separation cost
- recovering more biogas from wastes will positively impact the reduction of GHG emissions, especially from agriculture

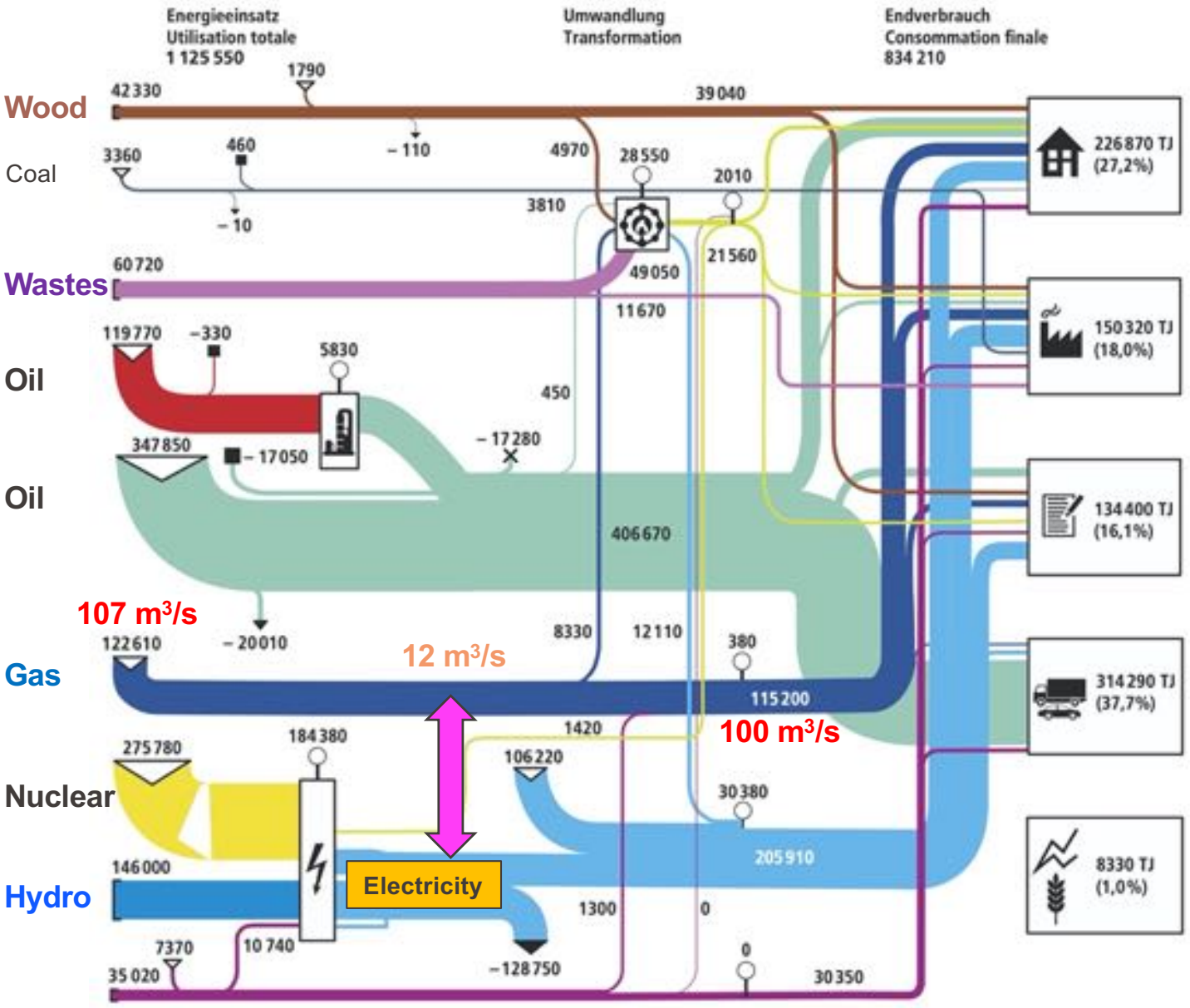
Innovation: Bio-electromethanation

- Methanation of CO_2 is electrocatalyzed **in a single step at ambient P & T, using microbes as renewable catalyst**. The microbes - **methanogenic bacteria** (*Archaea*) - act as electron bridges to reduce the high energy step from CO_2 to CH_4. Only a small amount of electrical energy is needed to maintain microbial conversion.

can boost gas to 80% CH_4 + 15% H_2

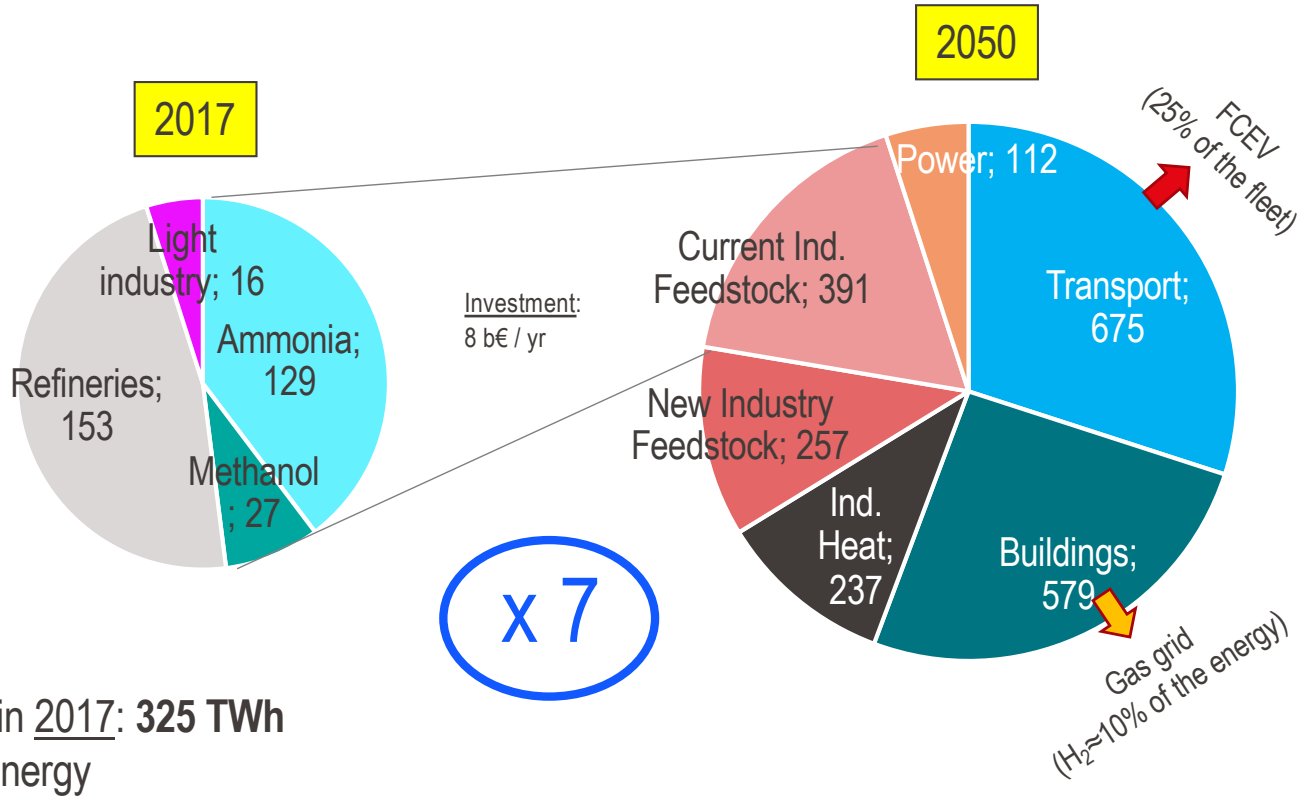


5. Hydrogen



Power-to-Gas
with
H_2

H_2 roadmap (EU) - TWh



Production H_2 in 2017: **325 TWh**
- 2% of final energy
- only in industry (chemical, petro)
- H_2 from fossil sources

2050: **2250 TWh**
- 24% of final energy
- multiple uses in all sectors

(equivalent electrolysis need* : **385 GWe)**

Adapted from : H2 ROADMAP EUROPE:
A SUSTAINABLE PATHWAY FOR THE EUROPEAN ENERGY TRANSITION
fch.europa.eu - January 2019

**100% load, 67% LHV efficiency electricity → H_2*
*>1100 GWe or **1.1 TWe** for electrolyser load of 3000h/yr*

European Gas network

Vested gas pipeline infrastructure.
42% of buildings are heated by NG.

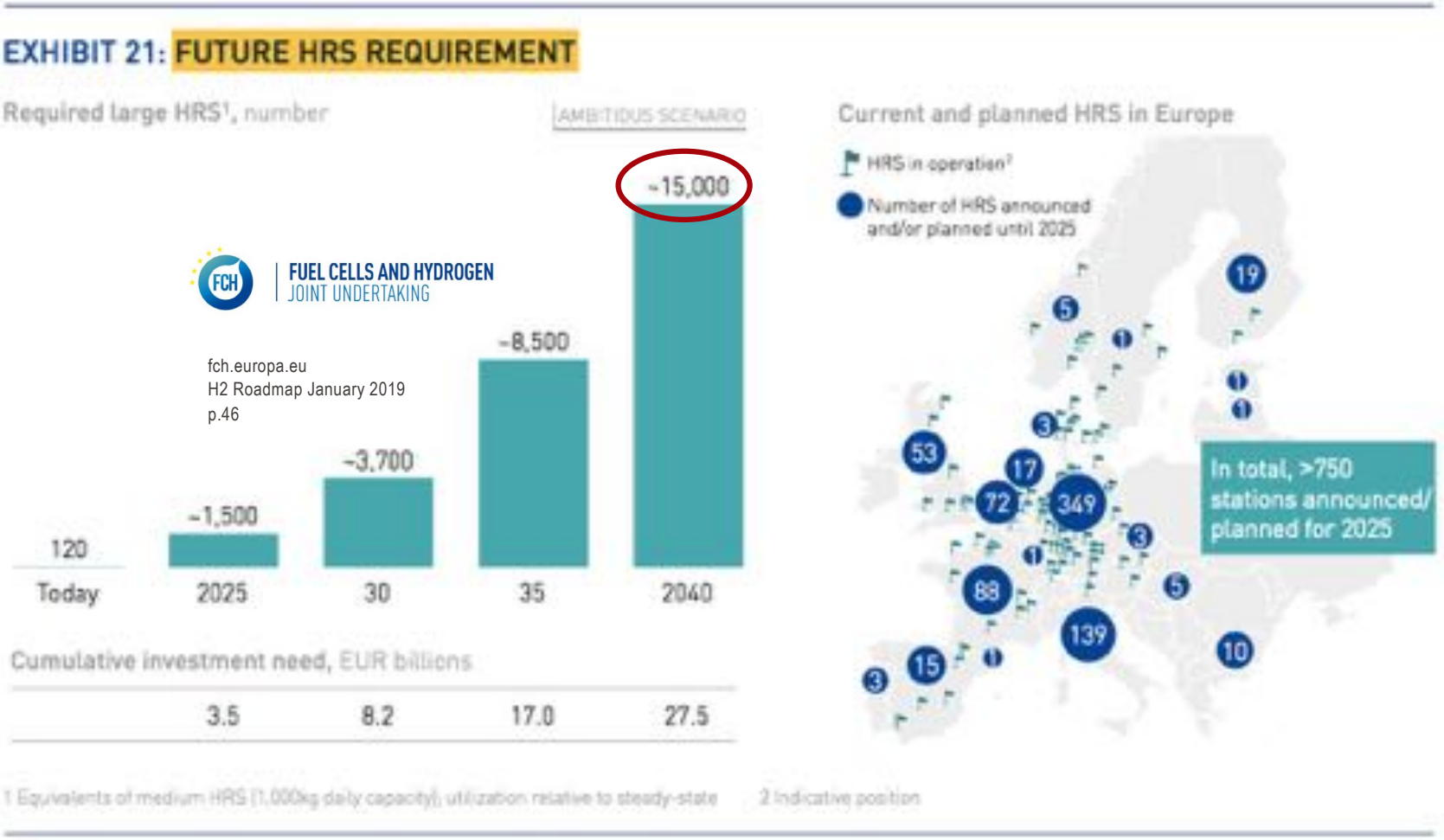
Gas consumption: 5375 TWh
(23% of EU energy) = 512 bio m^3 NG

Storage capacity: 1200 TWh
= large reserve for injection of H_2
(and biomethane)

10 vol% H_2 admixing:
= 51 bio m^3 H_2 = 169 TWh
>40 GWe electrolysis needed

Eurogas Statistical Report 2018

Mobility: H_2 refueling stations (HRS)



1000 kg H_2/day for 1 HRS

=> x 15'000 HRS = 15 Mt H_2/day = 5.5 Gt H_2/yr = 198 TWh >50 GWe electrolysis

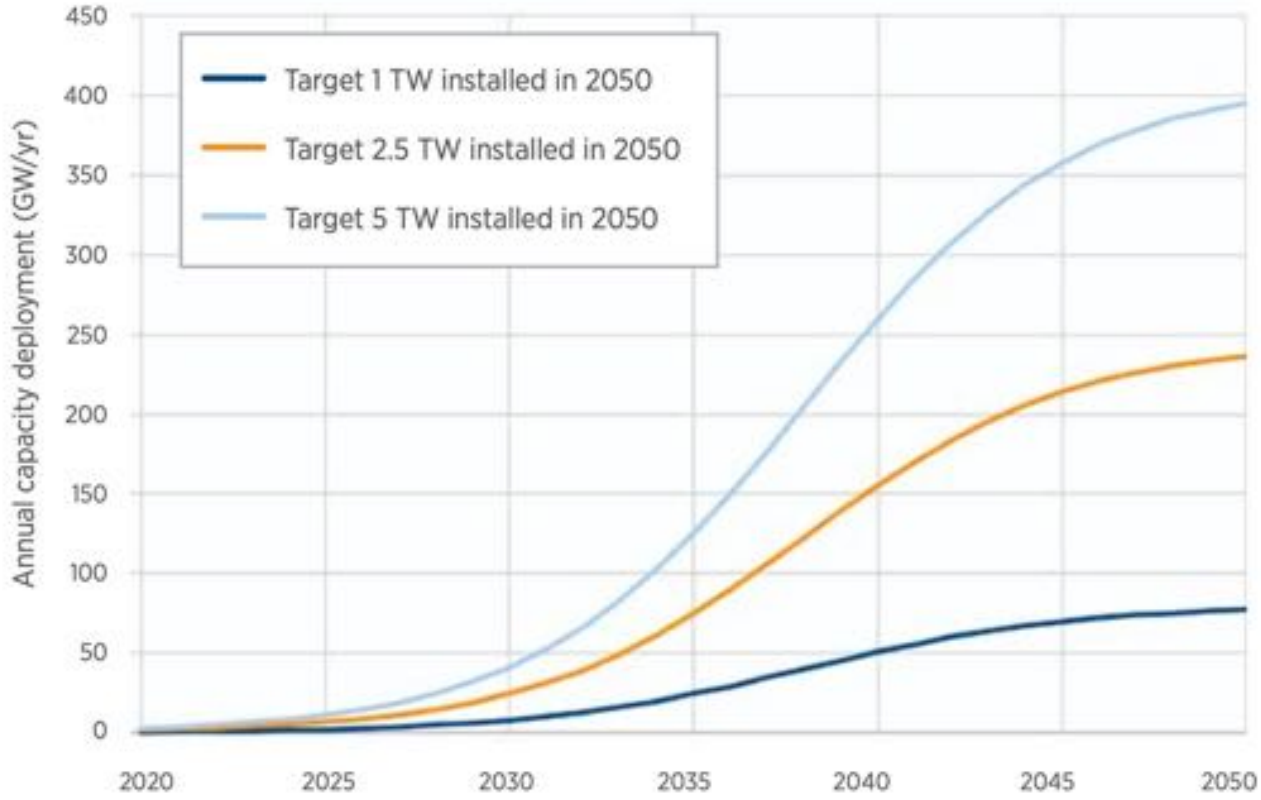
GWe/yr electrolyis deployment needed

=> TWe scale

Figure 32. Estimated necessary electrolyser manufacturing capacity (GW/year) to meet different installed capacity targets by 2050.

IRENA (2020), *Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.50C Climate Goal*, International Renewable Energy Agency. p.85

EU targets:
6 GWe – 2024
40 GWe – 2030



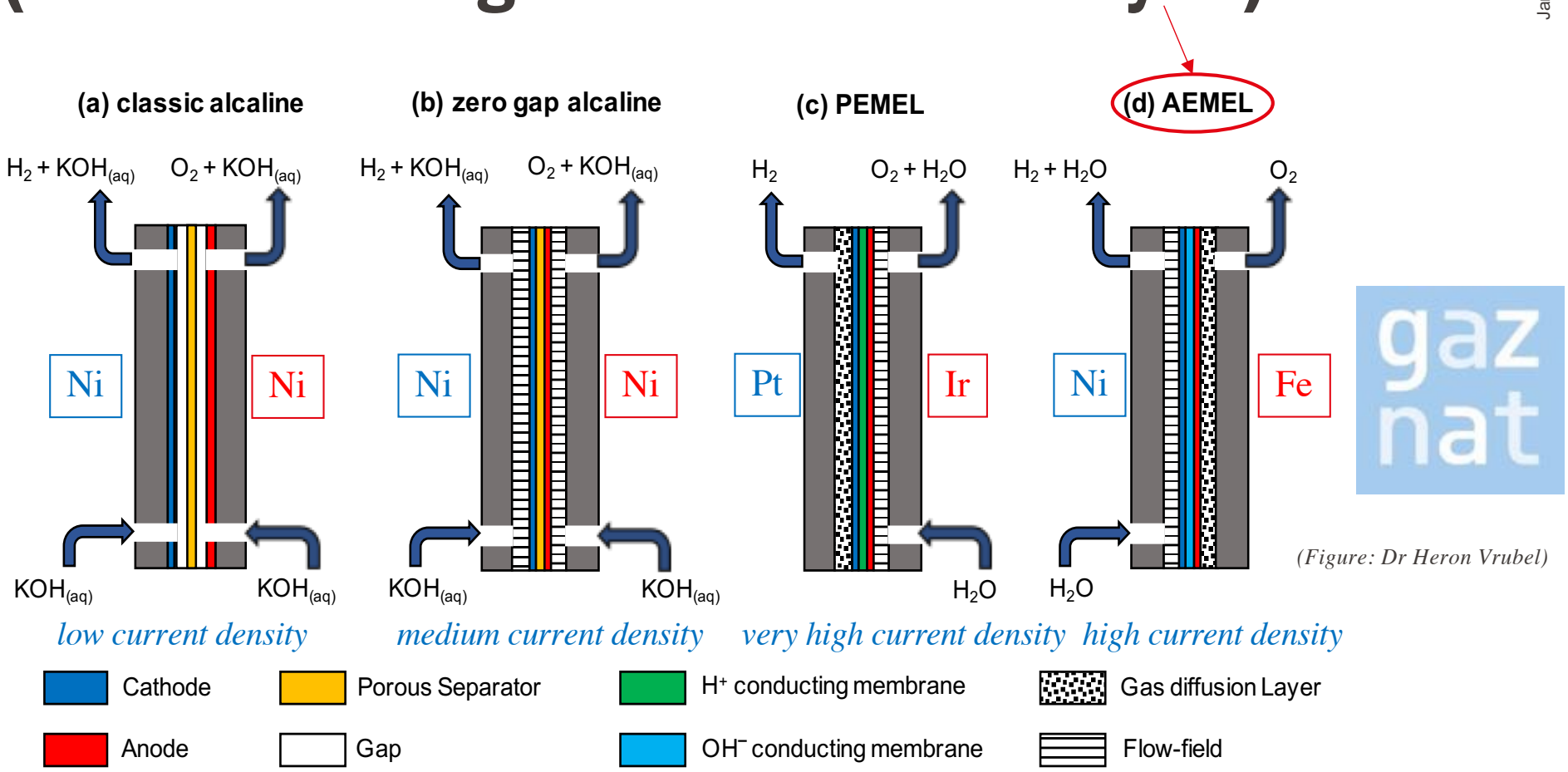
Important economies of scale above 1GWe/yr production

1 GWe (continuous electrolysis) abates 1 Mt CO_2/yr

H_2 deployment and use

- Large scale electrolysis is known :
  - Chlor-alkali industry 20 GWe (producing >50 TWh of H_2)
  - Aluminium industry >100 GWe (consumes 4% of the world electricity!)
- 2021 saw the 2 largest single electrolysers deployed (in Québec) : **20 MWe** PEMEL and **88 MWe** Alkaline Electrolysis (AEL)
- Grid injection : need standards
  - current regulations allow from 0.1% to 20% admixing of H_2 to NG grid
  - End-use technologies need a check (CNG cars, turbines, boilers,…)
  - Feed-in-tariff must be defined
  - at present 25 H_2 injection projects exist in Europe, mainly in Germany
- Mobility: like bio-CH_4, H_2 is best suited for larger vehicles (as range extension of battery-electric propulsion)
- Large scale H_2 can also decarbonize industry (steel, ammonia, petro,…)
- Critical materials are involved (Platinum Group Metals : Pt, Ir, Ru, ..)

Innovation : AEM (anionic exchange membrane electrolysis)



(Figure: Dr Heron Vrubel)

- no critical materials as catalysts
- alcaline medium (KOH) allows for (Ni-coated) **stainless steel** use (bipolar plates)
  (acidic medium (H^+) requires treated/coated (Au, Pt) **titanium** = more expensive)

Summary / Conclusions

Jan Van herle

Key facts and messages on the role of gas

- Keep and use the vested gas grid and infrastructure
  - for its multiple end-uses
    - in all sectors (HH, Services, Industry, Mobility)
    - for power generation
  - for progressive blending with renewable gases (green CH_4, H_2)
  - shows low distribution loss (0.8%) – unlike the electrical grid (7%)
- Difficult to replace in some sectors (e.g. industry process heat)
- It's itself a replacement for oil
- Can assist to bridge the 'electricity gap' (esp. winter)
  - clean, efficient, decentralised CHP via fuel cells
  - even with CO_2 separation/recycling
- Promote and support biogas/biomethane
  - up to 5% as injected bio-CH_4; ultimately up to 25% of NG replacement
  - for large vehicles (diesel replacement)
- **H_2** is key in the EU strategy (up to 24% of final energy in 2050)
  - for all sectors and uses
  - requires electrolysis deployment on a massive scale (with PV, wind, hydro)