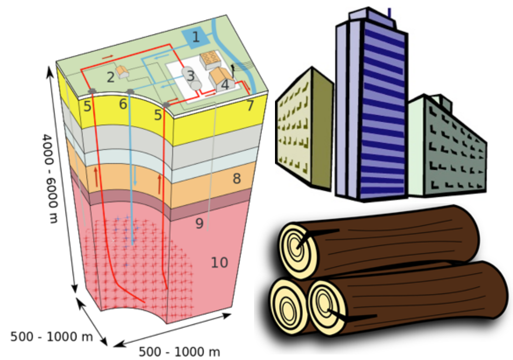

Geothermal Energy and Biomass Integration in Urban Systems: a Case Study

S. Moret*[,a], L. Gerber[b], F. Amblard[a], E. Peduzzi[a], F. Maréchal[a]

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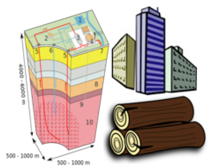
GEOTHERM2

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

OUTLINE

Outline:

- Introduction
- Methodology
- Models
- Scenarios
- Conclusions



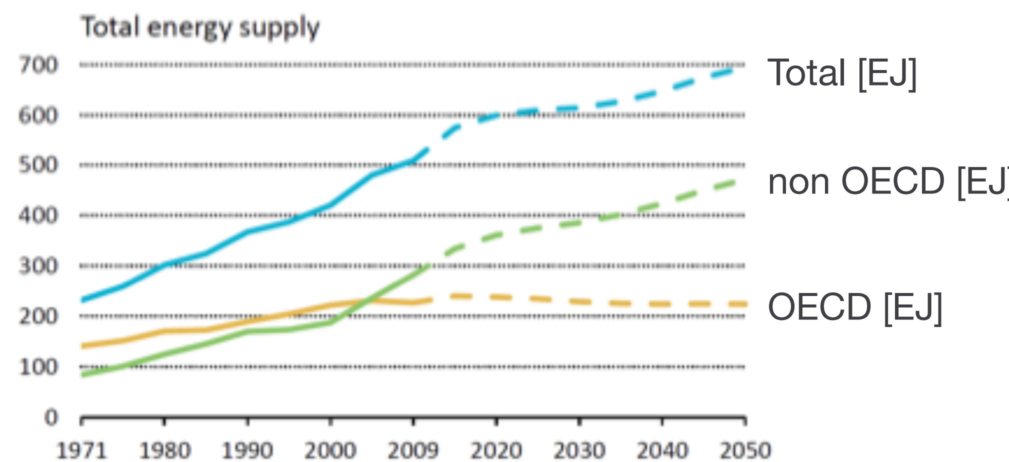
INTRODUCTION
The global context

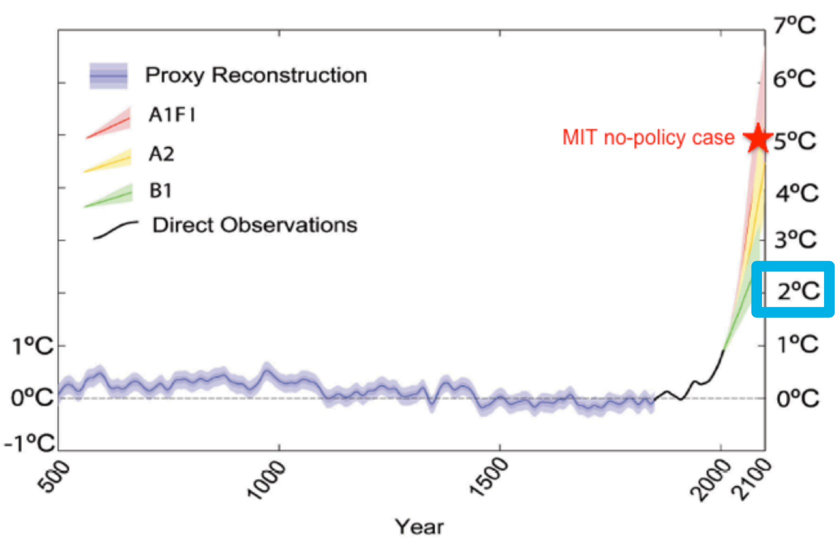
Sources:
- Copenhagen Diagnosis 2009, with MIT data taken from Sokolov et al. 2009.
- Jonathan Koomey, “Energy and society” lecture notes, UC Berkeley 2011
- IPCC 2013 report, Climate change 2013 - The physical science basis

[1] IEA, “Energy Technology Perspectives 2014,” IEA - International Energy Agency, 2014.

Growing trend in energy consumption, mainly from non OECD countries

CO_2 Emissions 2050 = **2x** emissions today



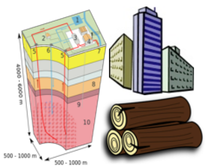


IPCC 2013: climate has changed due to human activities

To target the 2°C ΔT limit CO_2 emissions need to be halved by 2050

Challenge: **4x** emissions reduction by 2050

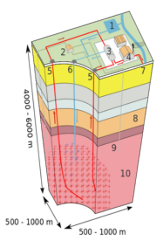
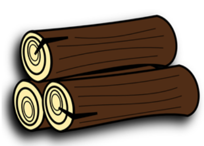
Introduction | Methodology | Models | Scenarios | Conclusions



INTRODUCTION
The global context

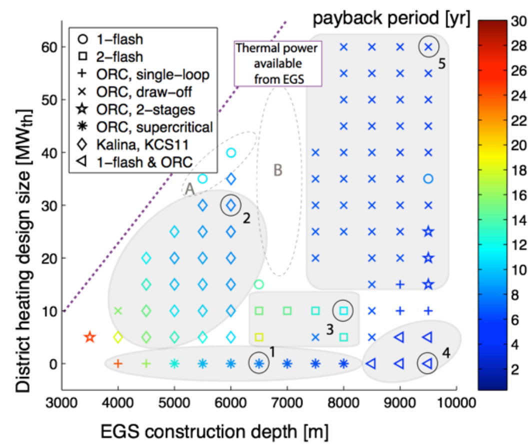
Sources:
[2] IPCC, Special Report on Renewable Energy Sources and Climate Change Mitigation. United Kingdom and New York, NY, USA: Cambridge University Press, 2011.
[3] J. Keirstead, M. Jennings, and A. Sivakumar, "A review of urban energy system models: Approaches, challenges and opportunities," Renew. Sustain. Energy Rev., vol. 16, no. 6, pp. 3847–3866, Aug. 2012.
[21] L. Gerber and F. Maréchal, "Environomic optimal configurations of geothermal energy conversion systems: Application to the future construction of Enhanced Geothermal Systems in Switzerland," Energy, vol. 45, no. 1, pp. 908–923, Sep. 2012.

Global primary energy consumption:

	Today	2050
	> **80%**	
	0.1% (2008)	3% el. 5% th.
	10.2% (2008)	~3x

50% of worldwide population
71% of energy related GHG

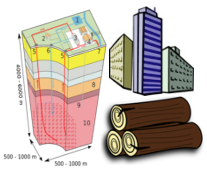
Geotherm I



Geotherm II

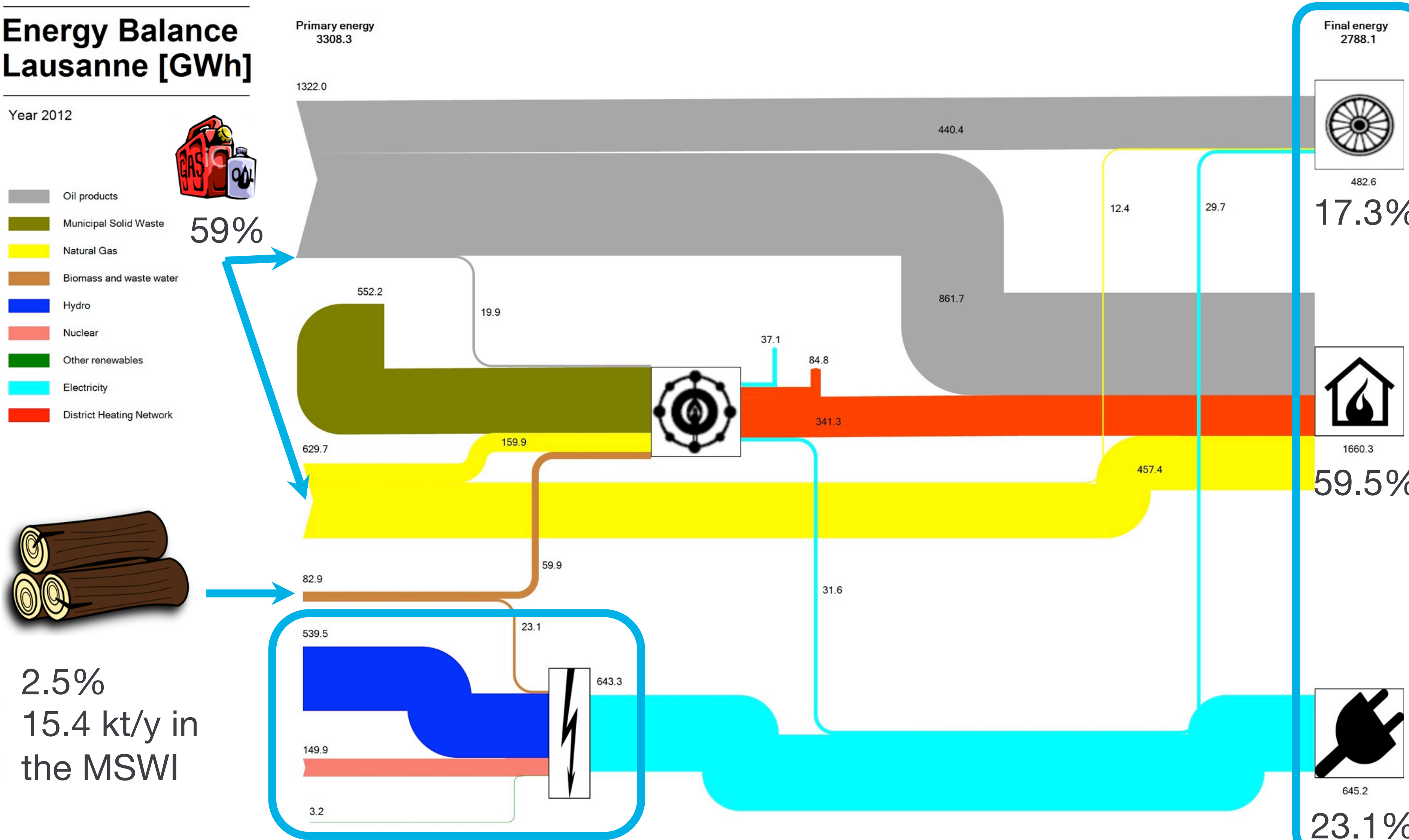
Geothermal energy integration in urban systems

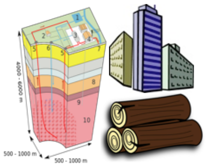
Introduction | Methodology | Models | Scenarios | Conclusions



INTRODUCTION
The case study of Lausanne

Energy Balance Lausanne [GWh]





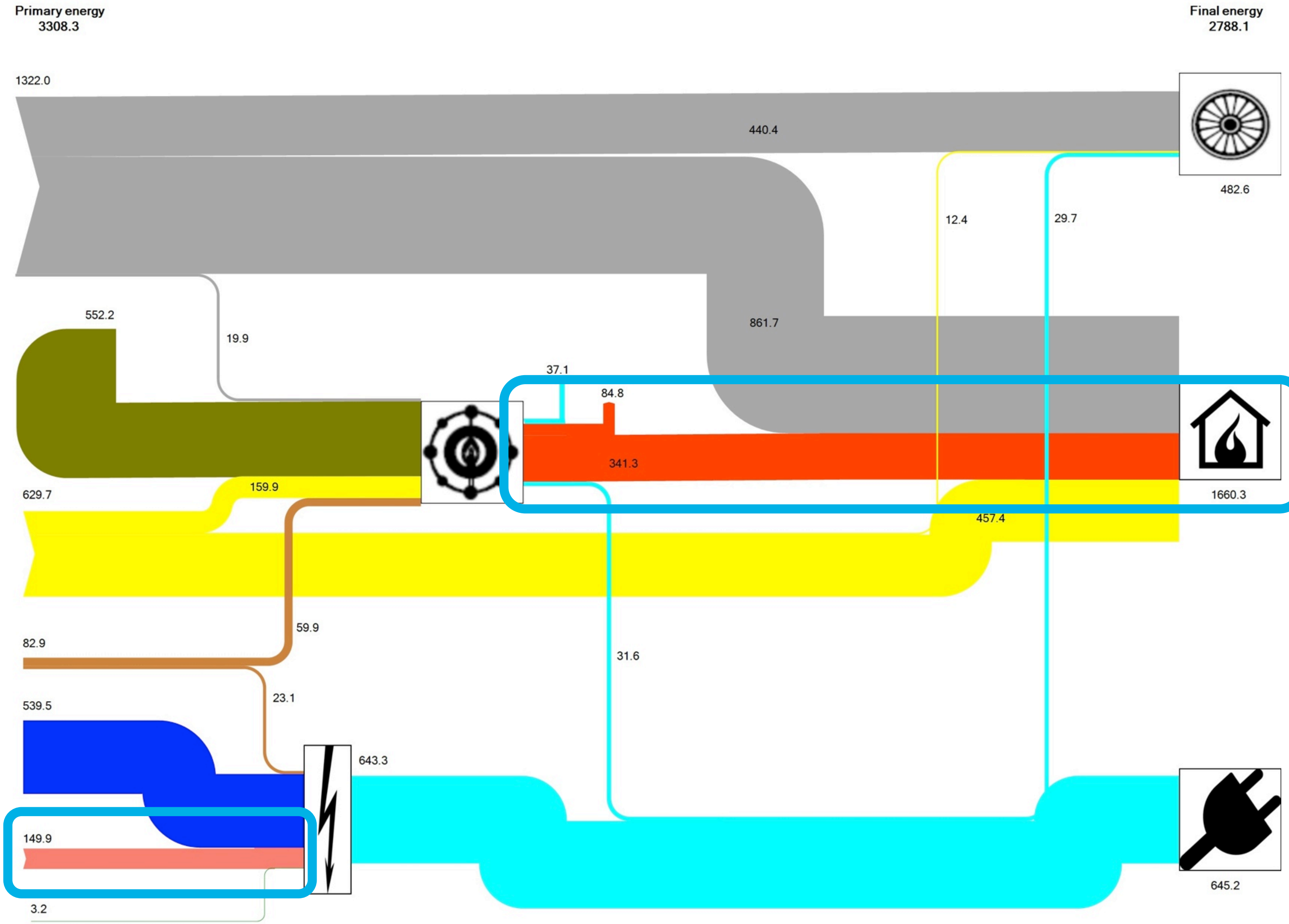
INTRODUCTION
The case study of Lausanne

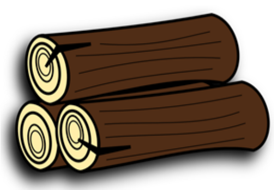
Sources:

[4] Swiss Federal Office of Energy, “Nuclear Energy,” 2013. [Online]. Available: www.bfe.admin.ch/themen/00511/index.html?lang=en. [Accessed: 27-Feb-2013].

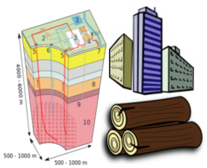
Energy Balance Lausanne [GWh]

Year 2012





Potential:
50-100 kt/y



INTRODUCTION
Literature review & Goals

Geothermal & Biomass integration:

- Strategic research priority in Europe
- Multi-objective optimization for urban systems (Gerber et al., 2013)
- Low-depth geothermal + HP, biogas and SNG from biomass (Alberg Østergaard et al., 2010)
- 35.5 MW_e hybrid plant (CA, USA)
- Hybrid NG-geothermal-biomass system for Cornell University (Lukawski et al., 2013)

Goals:

- Complete urban system model: current situation (2012) and future scenarios (2035)
- Geothermal and biomass options for the urban energy strategy
- Pinch analysis: integration of excess geothermal heat during the summer

[5] L. Gerber, S. Fazlollahi, and F. Maréchal, "A systematic methodology for the environomic design and synthesis of energy systems combining process integration, Life Cycle Assessment and industrial ecology," Comput. Chem. Eng., vol. 59, pp. 2–16, Dec. 2013.

[6] P. Alberg Østergaard, B. V. Mathiesen, B. Möller, and H. Lund, "A renewable energy scenario for Aalborg Municipality based on low-temperature geothermal heat, wind power and biomass," Energy, vol. 35, no. 12, pp. 4892–4901, Dec. 2010.

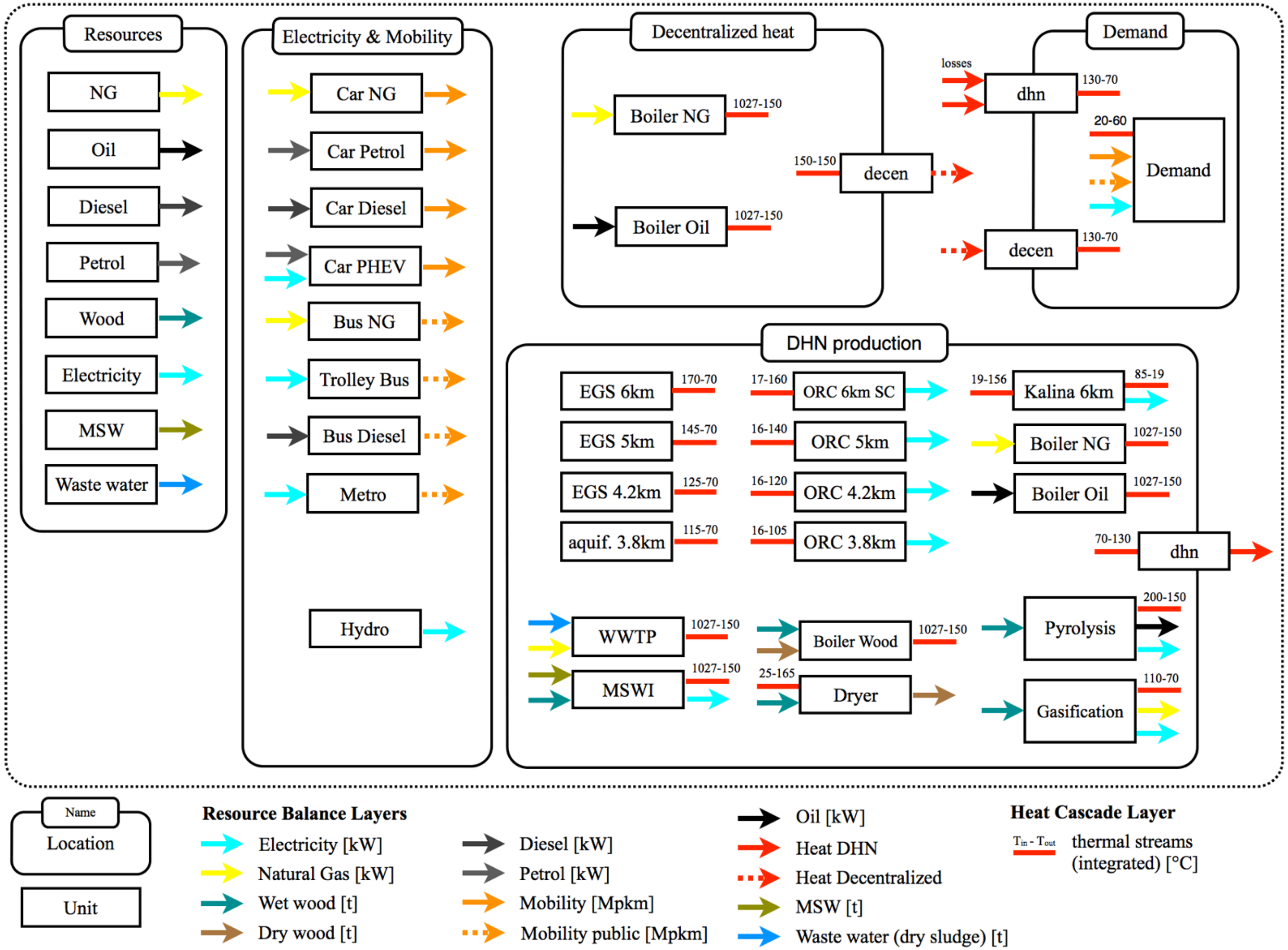
[7] H. Lund and E. Münster, "Modelling of energy systems with a high percentage of CHP and wind power," Renew. Energy, vol. 28, no. 14, pp. 2179–2193, Nov. 2003.

[8] E. Alakangas, G. Borgström, T. Felber, G. Göttlicher, P. Grammelis, J. Habart, W. Haslinger, R. Jansen, M. Martin, K. Mutka, and A. Weissinger, "Strategic Research Priorities for Biomass Technology," European Technology Platform on Renewable Heating and Cooling, 2012.

[9] J. W. Lund, K. Gawell, T. L. Boyd, and D. Jennejohn, "The United States of America Country Update 2010," presented at the Thirty-Fifth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA (USA), 2010, pp. 25–29.

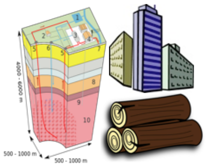
[10] M. Z. Lukawski, K. Vilaetis, L. Gkogka, K. F. Beckers, B. J. Anderson, and J. W. Tester, "A Proposed Hybrid Geothermal-Natural Gas-Biomass Energy System for Cornell University. Technical and Economic Assessment of Retrofitting a Low-Temperature Geothermal District Heating System and Heat Cascading Solutions," presented at the 38th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA (USA), 2013.

METHODOLOGY
Urban system model



Multiperiod problem

Period	Months	[h]
Summer	June to September	2928
Winter	November to March	3624
Mid-season	October, April, May	2208
Peak	-	0.01



METHODOLOGY
Performance indicators

Sources:
[11] Ecoinvent centre, "ecoinvent," 2014. [Online]. Available: http://ecoinvent.org.

Total Annual Cost [CHF_{2012}/year]: Annualized investment cost and maintenance for technologies (*tech*) + cost of resources (*res*: fuels and electricity imports)

$$C_{TOT} = C_{INV,an} + C_{OP} + C_{O\&M} = \sum_{tech} \frac{i(i+1)^{n_{tech}}}{(1+i)^{n_{tech}} - 1} C_{INV,tech} + \sum_{res} C_{OP,res} + \sum_{tech} C_{O\&M,tech}$$

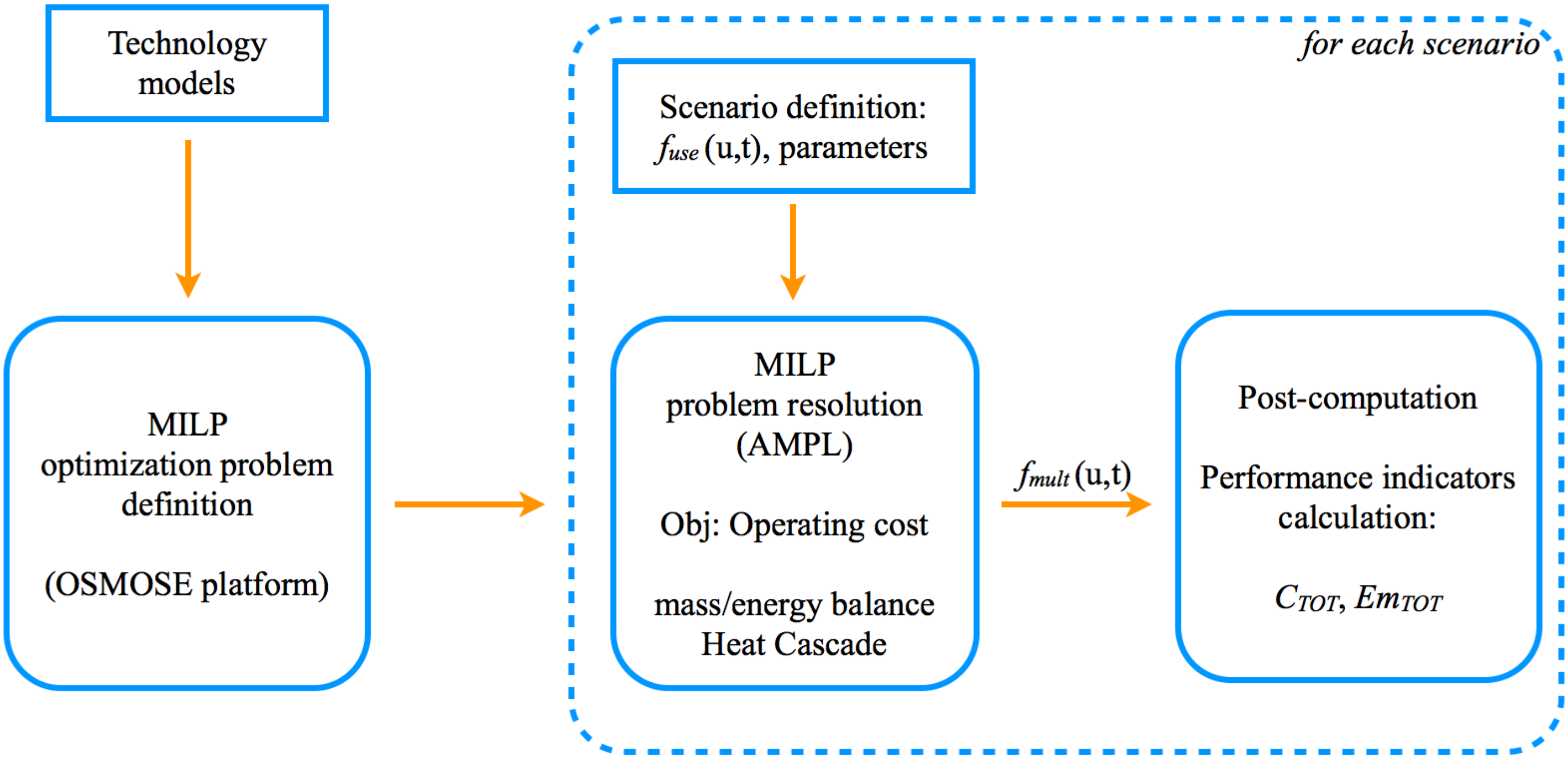
IPCC GWP 100a [$kt_{CO2\text{-}eq.}$/year]: LCA approach → emissions due to construction + emissions from reosources

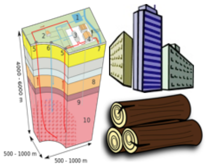
$$Em_{TOT} = Em_{constr,an} + Em_{OP} = \sum_{tech} \frac{Em_{constr,tech}}{n_{tech}} + \sum_{res} Em_{OP,res}$$

Advantage: indicators refer to the complete urban system → no need of assuming prices of heat/electricity within the system or of using avoided emissions

METHODOLOGY
Calculation framework

Sources:
[12] R. Bolliger, "Méthodologie de la synthèse des systèmes énergétiques industriels," Doctoral Thesis, EPFL, Lausanne, 2010.
[13] R. Fourer, D. Gay, and B. Kernighan, AMPL: A Modeling Language for Mathematical Programming. Duxbury Press, 2002.
[14] F. Maréchal and B. Kalitventzeff, "Process integration: Selection of the optimal utility system," Comput. Chem. Eng., vol. 22, Supplement 1, pp. S149–S156, Mar. 1998.

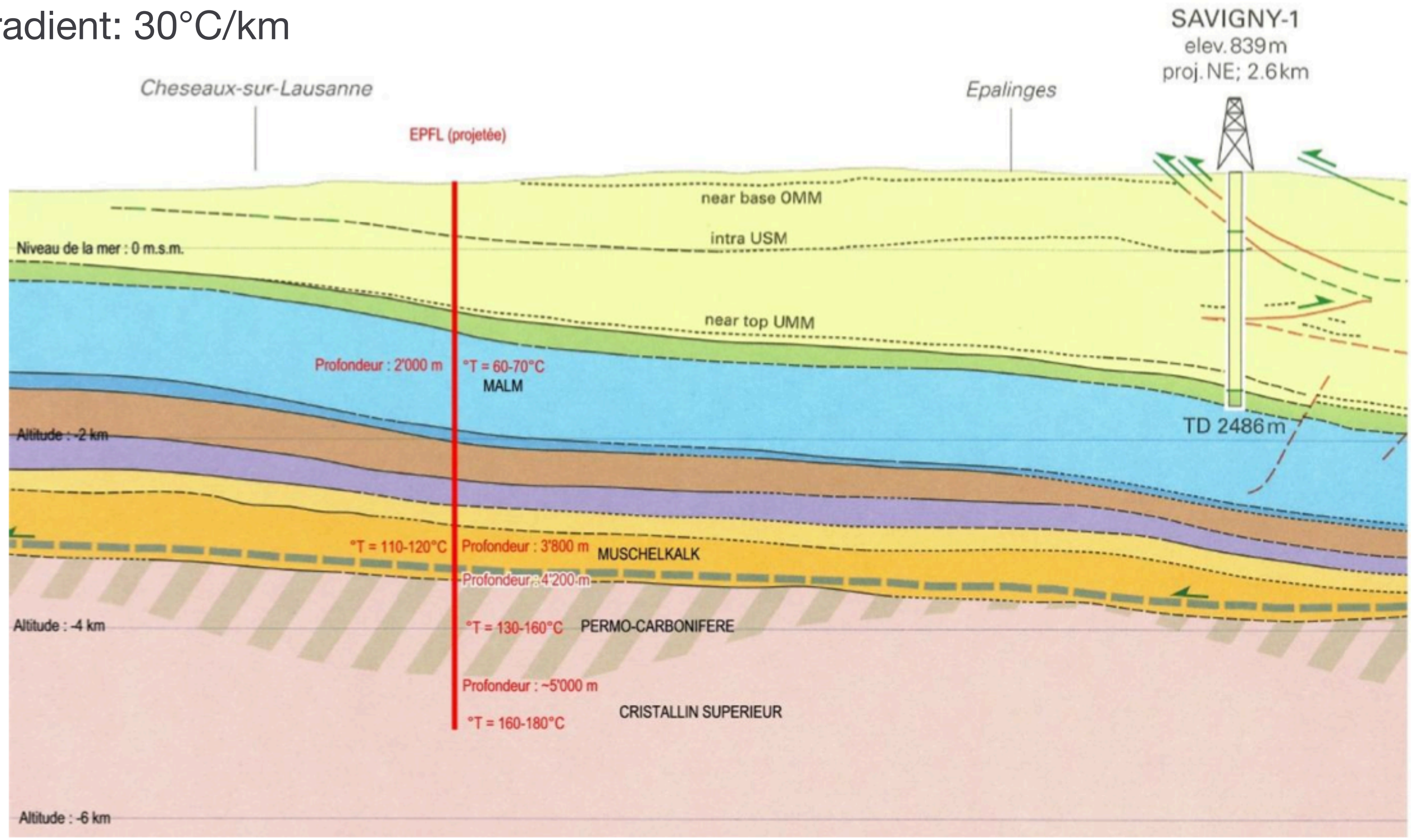




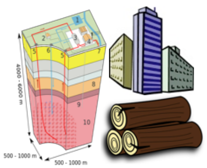
MODELS
Geothermal

Sources:
- Tacher, Laurent. An attempt of deep geological stratigraphical model in the area of Lausanne city. 2014.

Gradient: 30°C/km



Introduction | Methodology | Models | Scenarios | Conclusions



MODELS Geothermal

Sources:
[19] Working group PDGN, “Programme cantonal de développement de la géothermie à Neuchâtel: Rapport final,” Laboratoire Suisse de Géothermie - CREGE, Switzerland, 2010.
[20] K. F. Beckers, M. Z. Lukawski, B. J. Anderson, M. C. Moore, and J. W. Tester, “Levelized costs of electricity and direct-use heat from Enhanced Geothermal Systems,” J. Renew. Sustain. Energy, vol. 6, no. 1, p. 013141, Jan. 2014.
[21] L. Gerber and F. Maréchal, “Environomic optimal configurations of geothermal energy conversion systems: Application to the future construction of Enhanced Geothermal Systems in Switzerland,” Energy, vol. 45, no. 1, pp. 908–923, Sep. 2012.
[22] L. Gerber and F. Maréchal, “Defining optimal configurations of geothermal systems using process design and process integration techniques,” Appl. Therm. Eng., vol. 43, pp. 29–41, Oct. 2012.

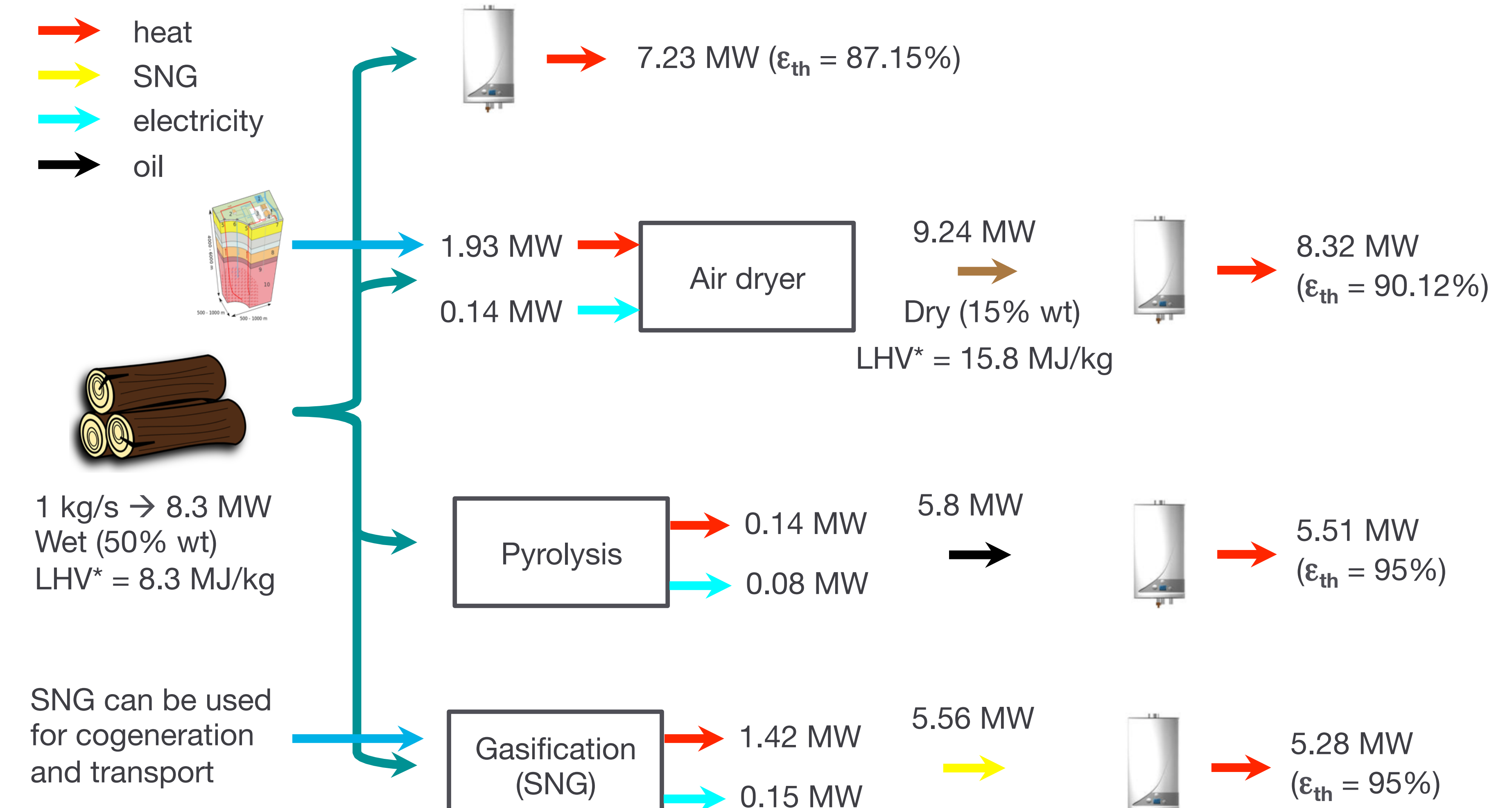
Resource	Depth [km]	Mass flow [kg/s]	Pump [kW]	Heat [kW]	T_{well}/T_{inj} [°C]	C_{INV} [MCHF]	$C_{O\&M}$ [MCHF/y]
Malm	2	25 [19]	30.1 [20]	3780 [22]	65/29 [22]	9.64 [20]	-
Muschelkalk	3.8	13.5 [19]	3.5 [20]	2552 [22]	115/70 [20]	21.79 [20]	0.398 [20]
EGS	4.2	100 [20]	1231 [20]	22841 [20]	125/70 [20]	37.93 [20]	1.407 [20]
EGS	5	100 [20]	1180 [20]	31241 [20]	145/70 [20]	49.16 [20]	1.832 [20]
EGS	6	100 [20]	1053 [20]	41793 [20]	170/70 [20]	64.74 [20]	2.405 [20]

Energy conversion cycles:

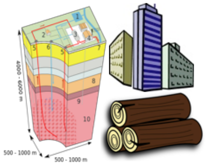
Cycle	Fluid	ε_{el} [-]
ORC SC 6 km	R134a	18.1%
ORC 5 km	R134a	14.9%
ORC 4.2 km	R134a	13.1%
ORC 3.8 km	R134a	13.2%
Kalina 6 km	NH_3/H_2O	12.3%

MODELS
Woody biomass

Sources:
[17] Biomass energy centre, 2014. [Online]. Available: http://www.biomassenergycentre.org.uk/
[5] L. Gerber, S. Fazlollahi, and F. Maréchal, "A systematic methodology for the environomic design and synthesis of energy systems combining process integration, Life Cycle Assessment and industrial ecology," Comput. Chem. Eng., vol. 59, pp. 2–16, Dec. 2013.
[23] Belsim, "Belsim company website," 2014. [Online]. Available: http://www.belsim.com.



*LHV on a wet basis



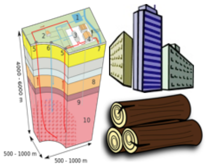
MODELS
Woody biomass

Sources:
[11] Ecoinvent centre, "ecoinvent," 2014. [Online]. Available: http://ecoinvent.org.
[5] L. Gerber, S. Fazlollahi, and F. Maréchal, "A systematic methodology for the environomic design and synthesis of energy systems combining process integration, Life Cycle Assessment and industrial ecology," Comput. Chem. Eng., vol. 59, pp. 2–16, Dec. 2013.
[25] R. W. R. Zwart, H. Boerrigter, E. P. Deurwaarder, C. M. van der Meijden, and S. V. B. van Paasen, "Production of Synthetic Natural Gas (SNG) from Biomass," ECN - Energy research Center of the Netherlands, 2006.
[26] A. Uslu, A. P. C. Faaij, and P. C. A. Bergman, "Pre-treatment technologies, and their effect on international bioenergy supply chain logistics. Techno-economic evaluation of torrefaction, fast pyrolysis and pelletisation," *Energy*, vol. 33, no. 8, pp. 1206–1223, Aug. 2008.

Model	**Lifetime**	**$C_{INV,1}$ [MCHF]**	**$C_{INV,2}$ [MCHF]**	**GWP [$t_{CO2\text{-}eq}$/unit]**
Wood boiler	25	1.302 [5]	9.75 [5]	99.96 [11]
Air dryer	50 [11]	0	1.07	76.16
Pyrolysis	25	0	10.44 [26]	181.1
Gasification	25	0	36 [25]	27.98

Modeling of the demand (2012):

Period	**Electricity [MW]**	**Heating [MW]**		**Transportation [Mpkm]**	
		DHN	**Decentralized**	**Private**	**Public**
Summer	59.46	18.07	59.81	207.0	852.7
Winter	83.02	63.73	210.9	207.0	852.7
Mid-season	77.13	31.11	102.3	207.0	852.7
Peak	124.7	108.5	410.85	207.0	852.7

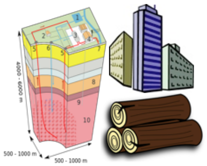


SCENARIOS
Scenario list

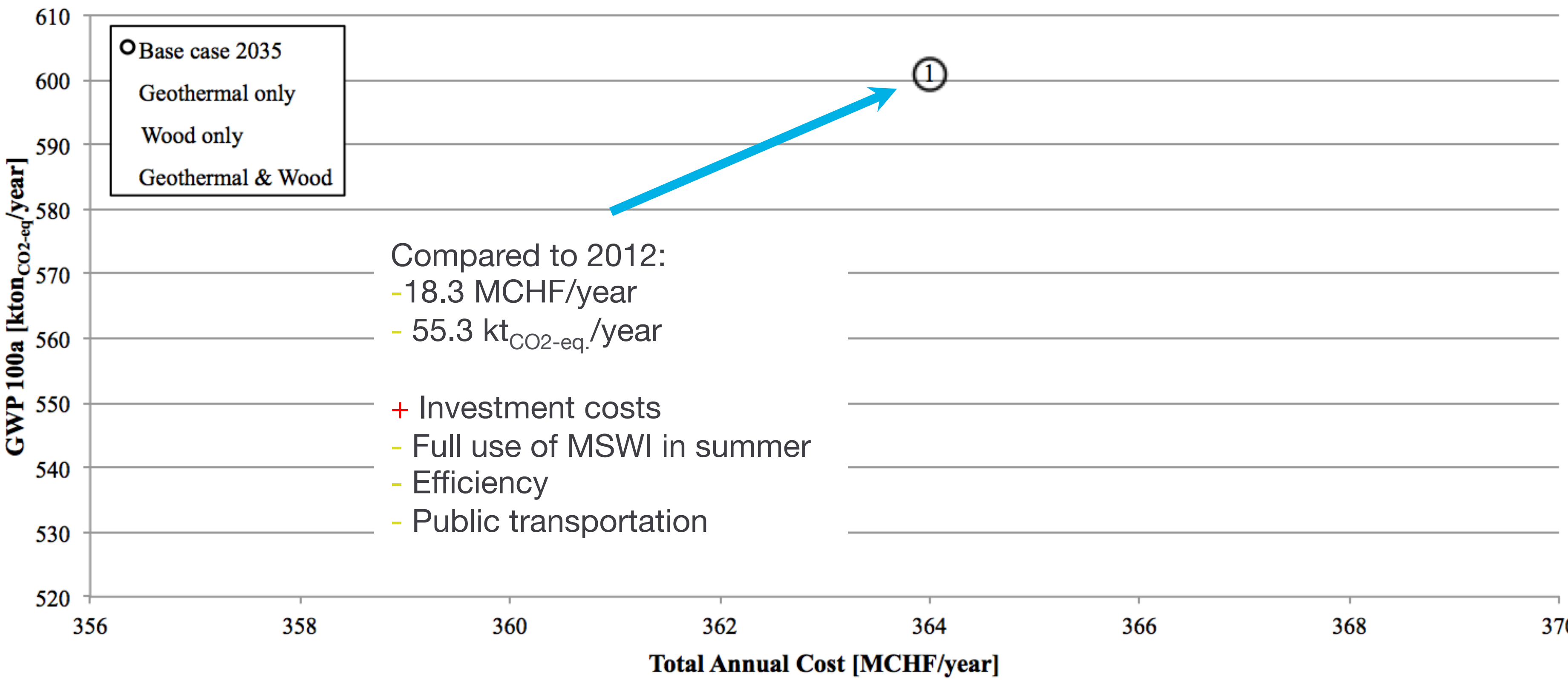
2012 → 2035

- Population growth: +0.7%/year
- DHN: +2%/year
- Same overall heat demand
- Same transportation and electricity demand per capita
- Public transportation: 19.5% → 28.5%
- Increased efficiencies for boilers and transportation
- +31 MW_e hydroelectric turbine
- Higher share of gas boilers in decentralized
- Electricity import: 20% CCGT + renewables

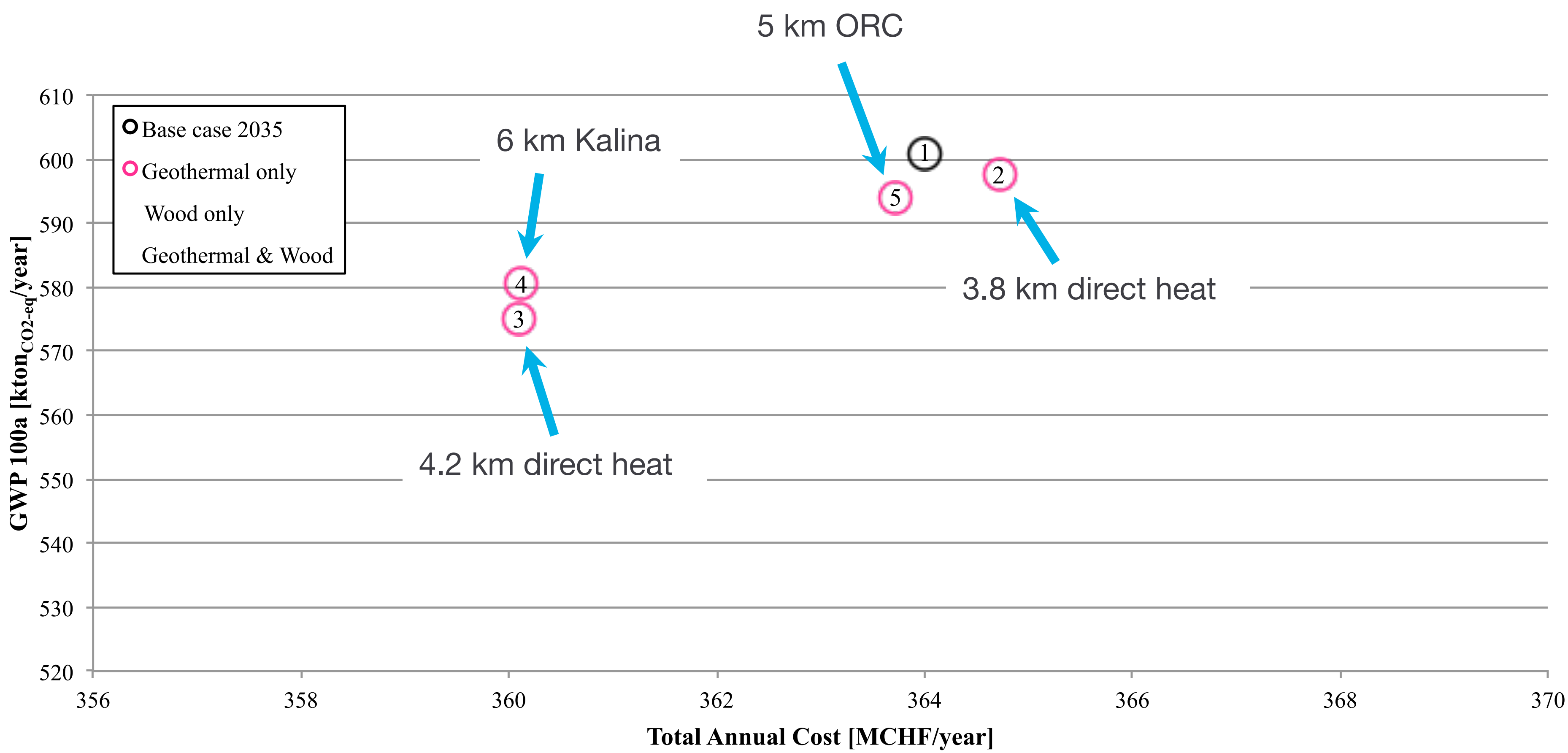
#	Year	Woody Biomass	Geothermal
0	2012	15.4 kt/y MSWI	-
1	2035	15.4 kt/y MSWI	-
2	2035	15.4 kt/y MSWI	3.8 km direct use
3	2035	15.4 kt/y MSWI	4.2 km direct use
4	2035	15.4 kt/y MSWI	6 km Kalina
5	2035	15.4 kt/y MSWI	5 km ORC
6	2035	100 kt/y Boiler (wet)	-
7	2035	100 kt/y Boiler (dry)	-
8	2035	100 kt/y pyrolysis	-
9	2035	100 kt/y gasification	-
10	2035	100 kt/y pyrolysis	4.2 km direct use
11	2035	100 kt/y pyrolysis	4.2 km ORC
12	2035	100 kt/y pyrolysis	6 km Kalina
13	2035	100 kt/y gasification	5 km direct use
14	2035	100 kt/y gasification	6 km Kalina
15	2035	100 kt/y gasification	3.8 km ORC
16	2035	100 kt/y Boiler (dry)	6 km ORC
17	2035	100 kt/y Boiler (dry)	4.2 km direct use



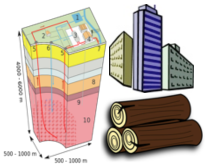
SCENARIOS
Results



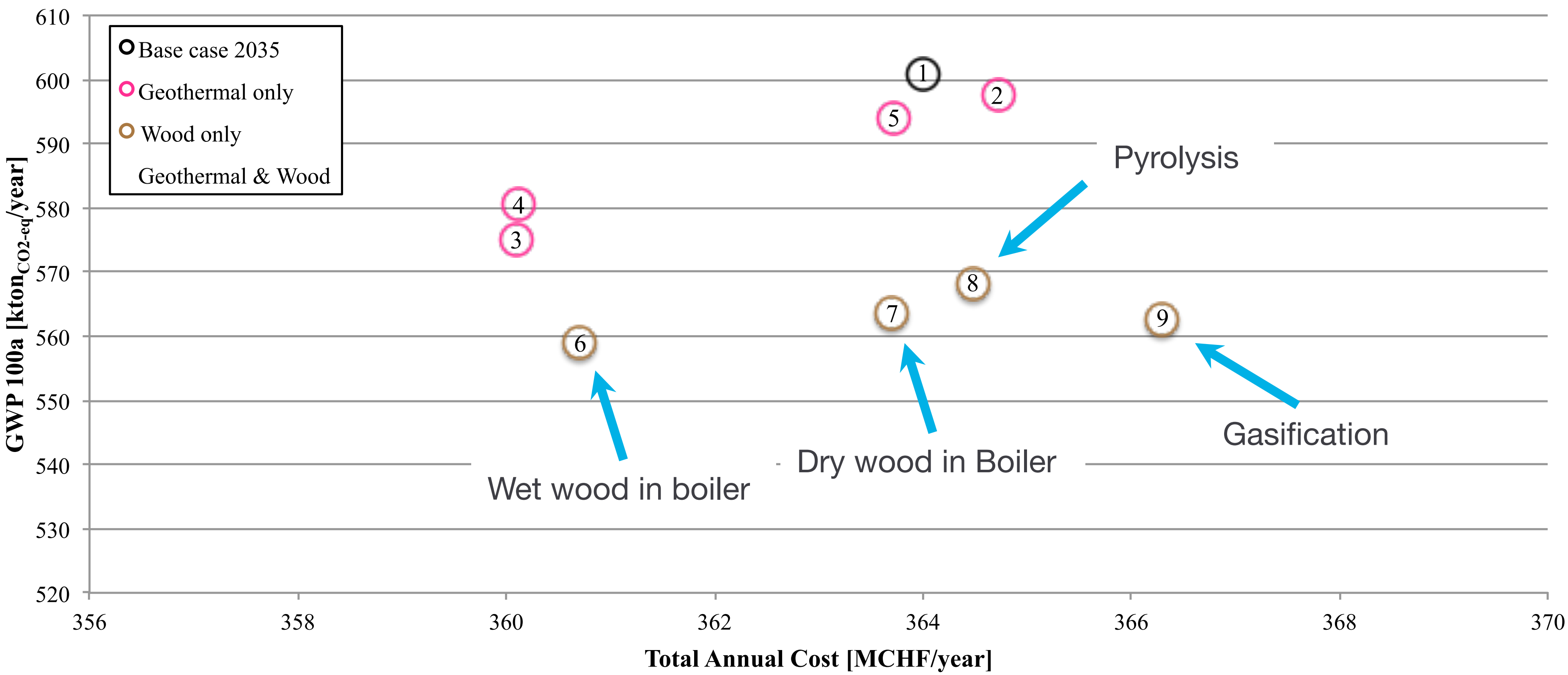
SCENARIOS
Results



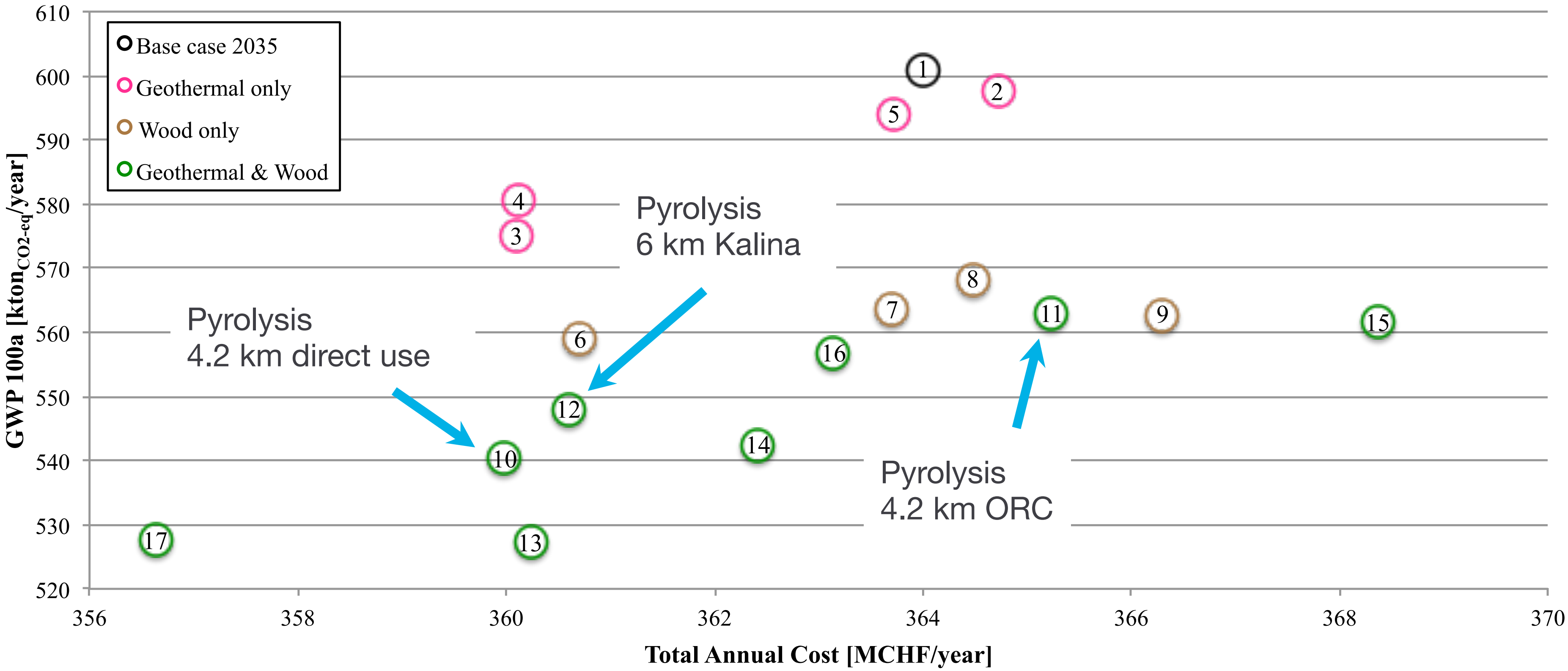
Introduction | Methodology | Models | Scenarios | Conclusions



SCENARIOS
Results

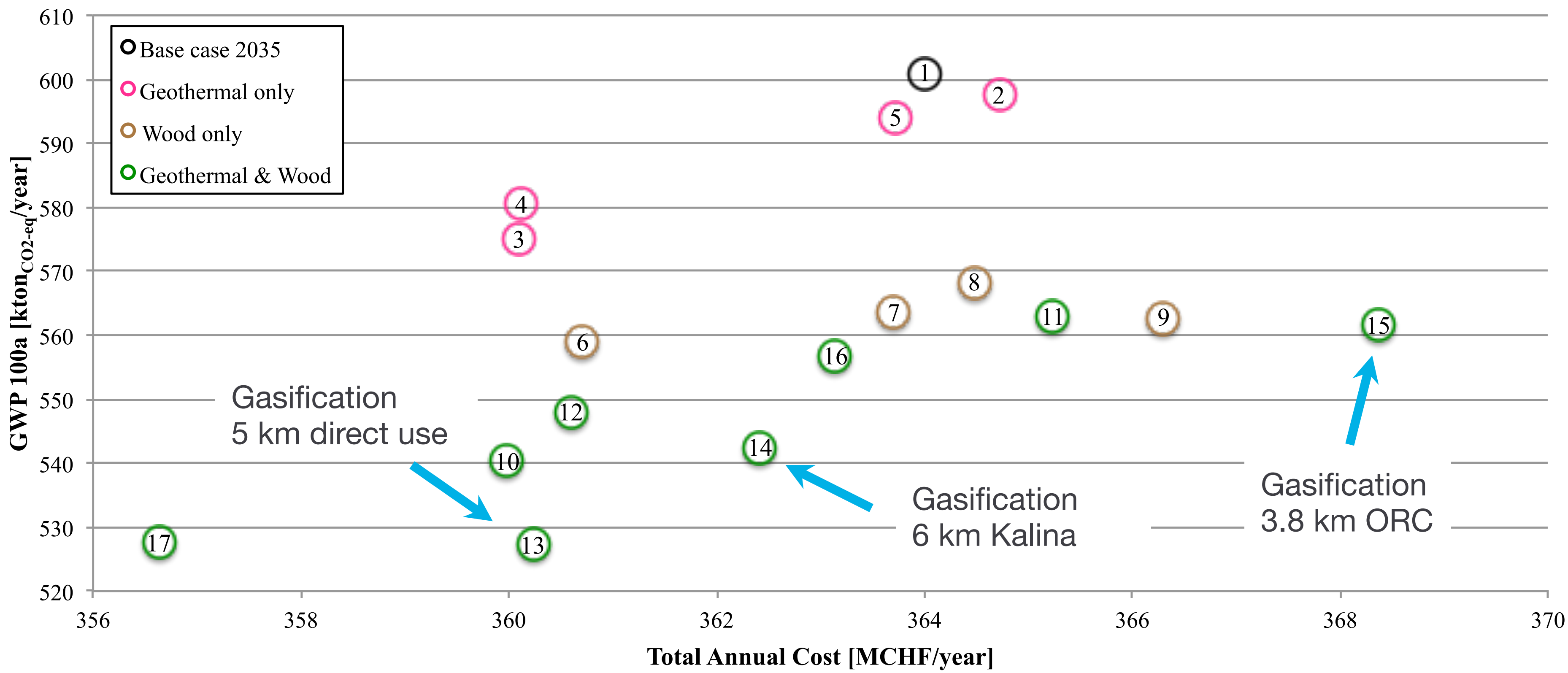


SCENARIOS
Results

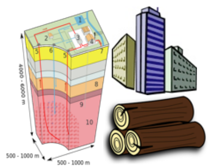


Introduction | Methodology | Models | Scenarios | Conclusions

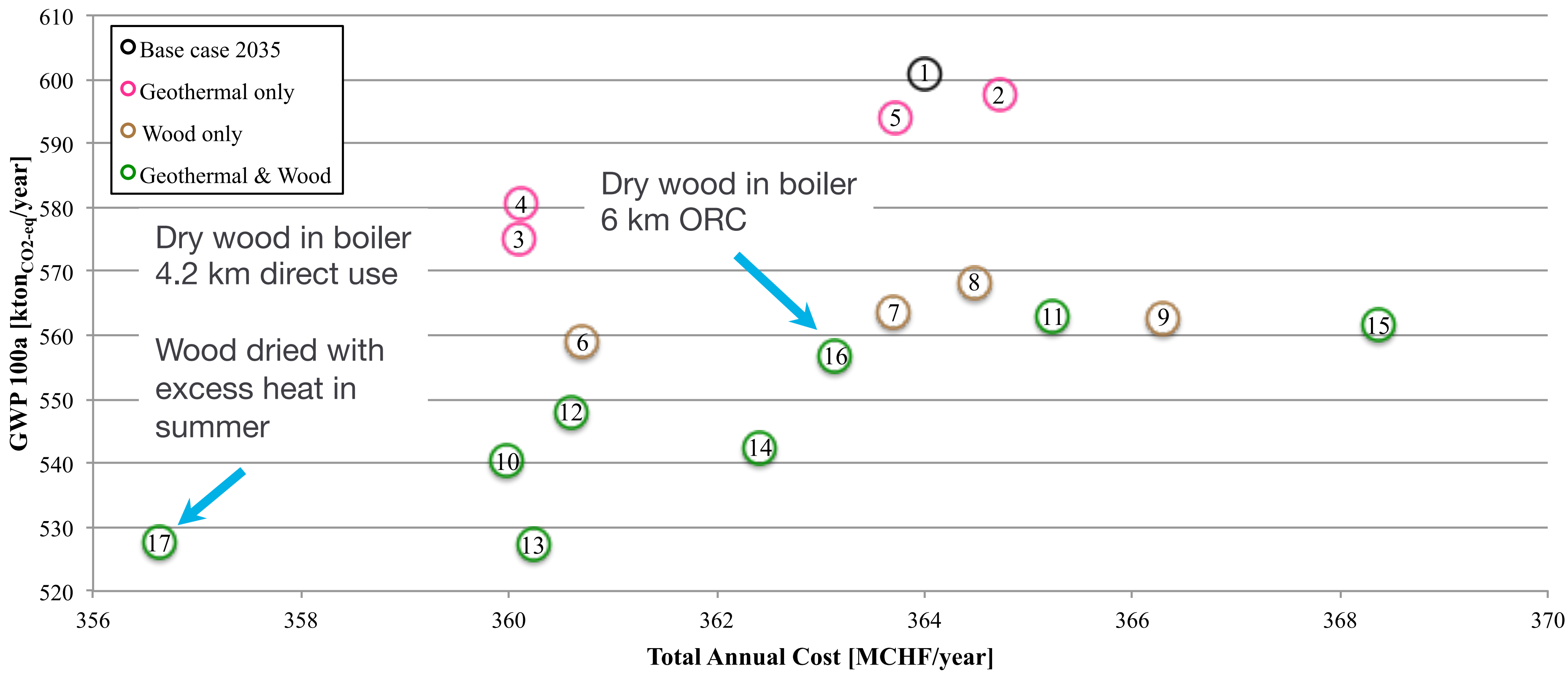
SCENARIOS
Results

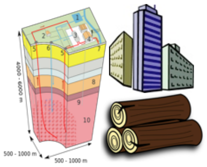


Introduction | Methodology | Models | Scenarios | Conclusions

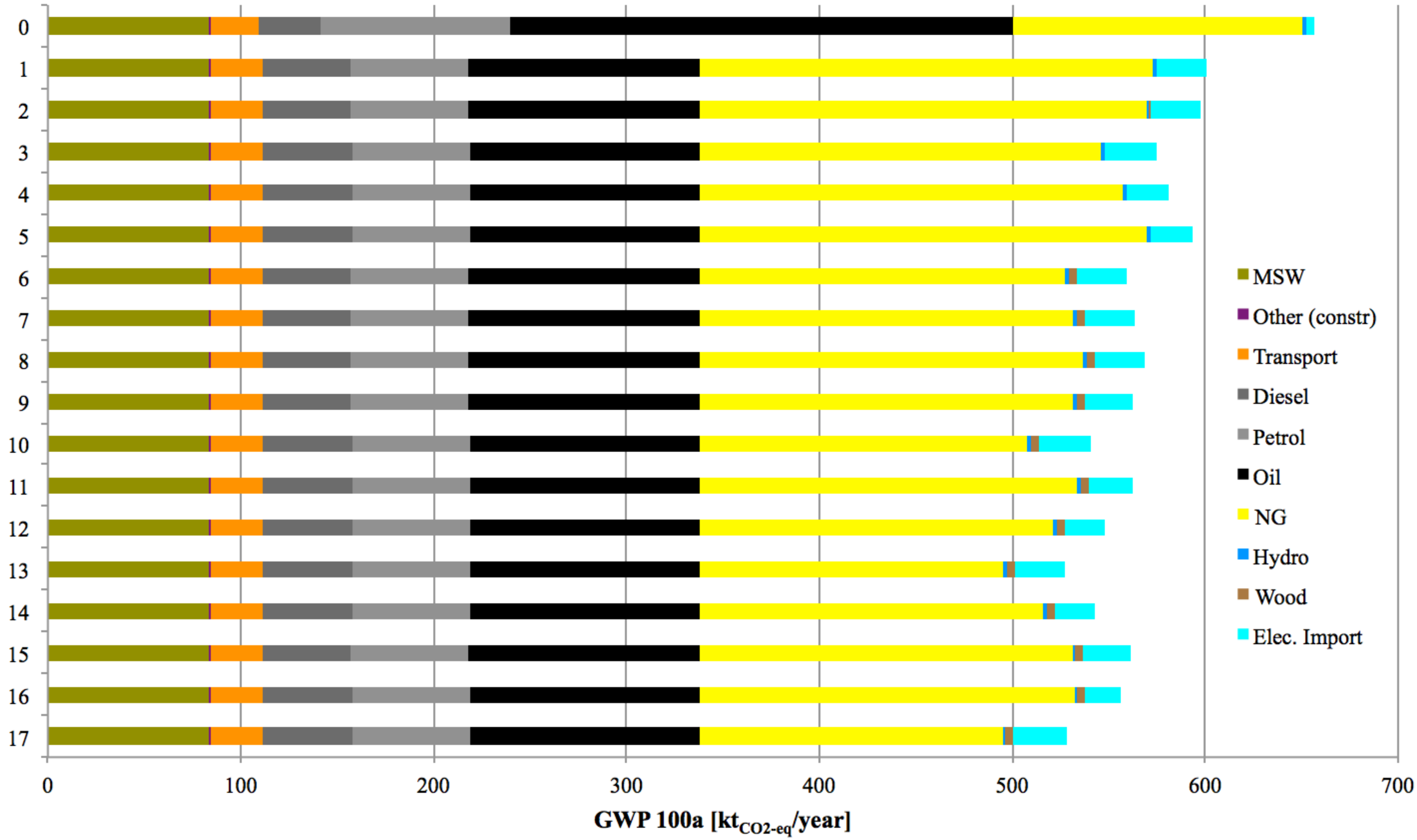


SCENARIOS
Results

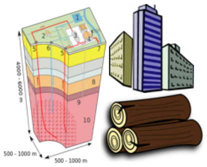




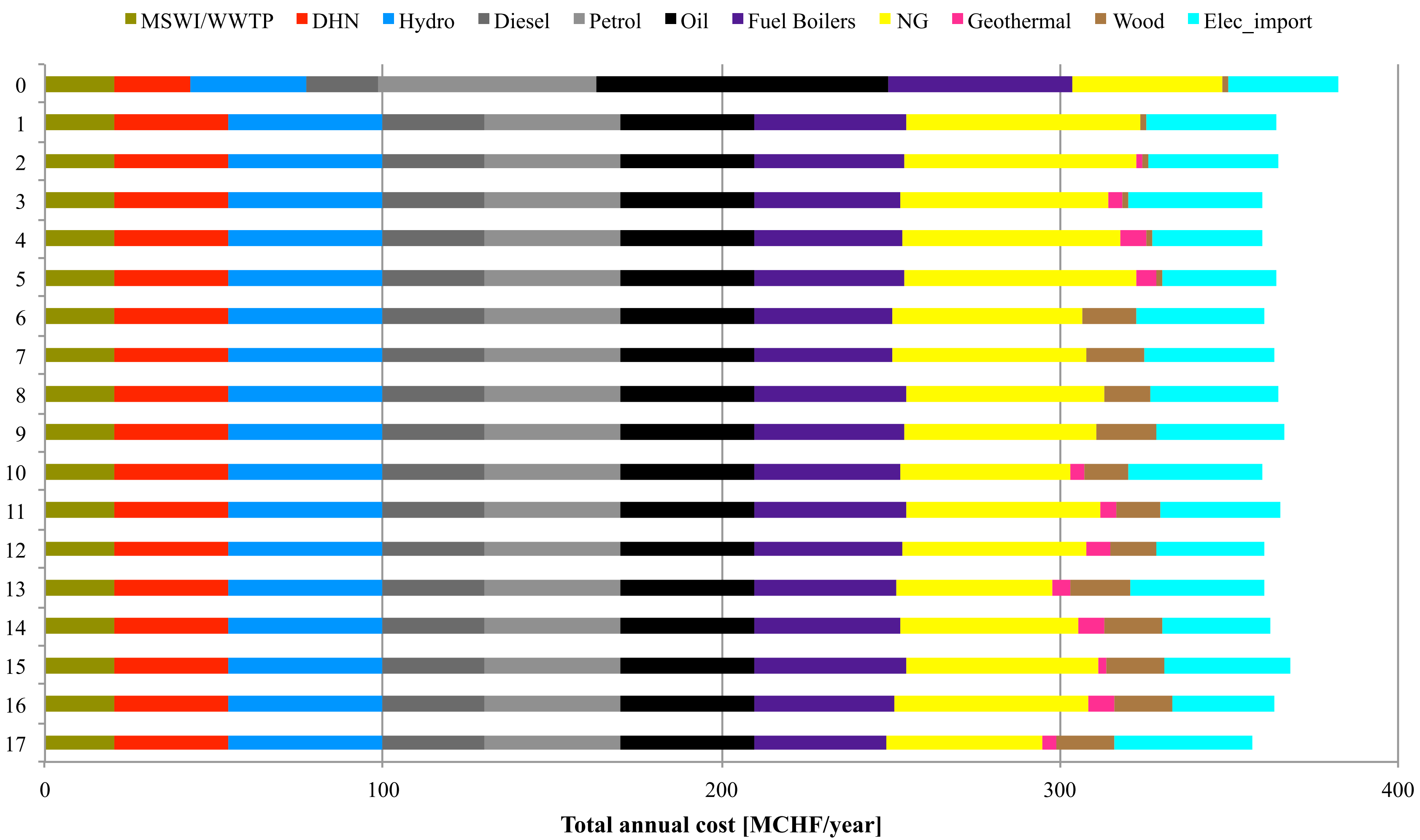
SCENARIOS
Results – GWP 100a breakdown



Introduction | Methodology | Models | Scenarios | Conclusions

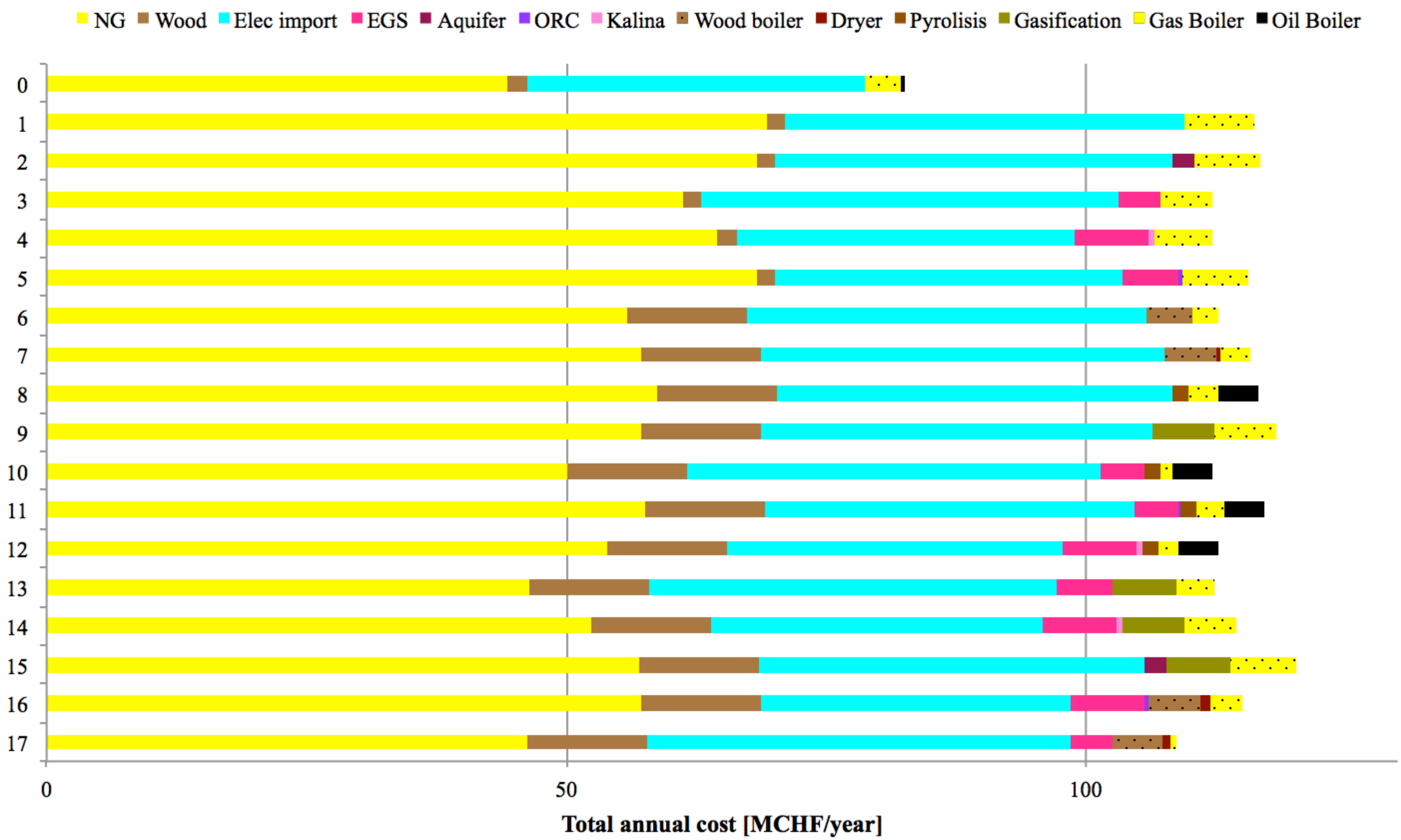


SCENARIOS
Results – Total Annual Cost breakdown

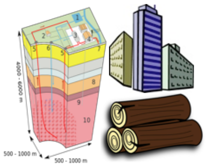


Introduction | Methodology | Models | Scenarios | Conclusions

SCENARIOS
Results – Total Annual Cost breakdown

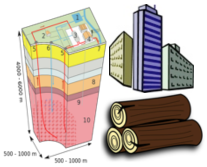


Introduction | Methodology | Models | Scenarios | Conclusions



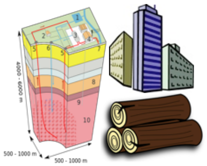
CONCLUSIONS
Conclusions

- Complete model of a urban energy system → strategic energy planning
- Geothermal: direct use is the most interesting option, followed by cogeneration. ORC is less interesting
- Biomass: If combustion is considered, burning wood for DHN supply is the best option. Gasification to SNG allows substitution in transportation and efficient cogeneration
- Interesting option (low CAPEX) is the use of excess heat in summer for wood drying → storage of the excess heat for combustion during winter (100% renewable DHN)



CONCLUSIONS
Future work

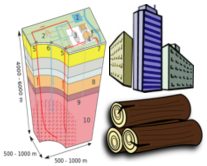
- Inclusion of logistics, storage and other energy conversion options
- Unique MILP formulation for urban systems planning
- Increased spatial and temporal resolution
- Uncertainty



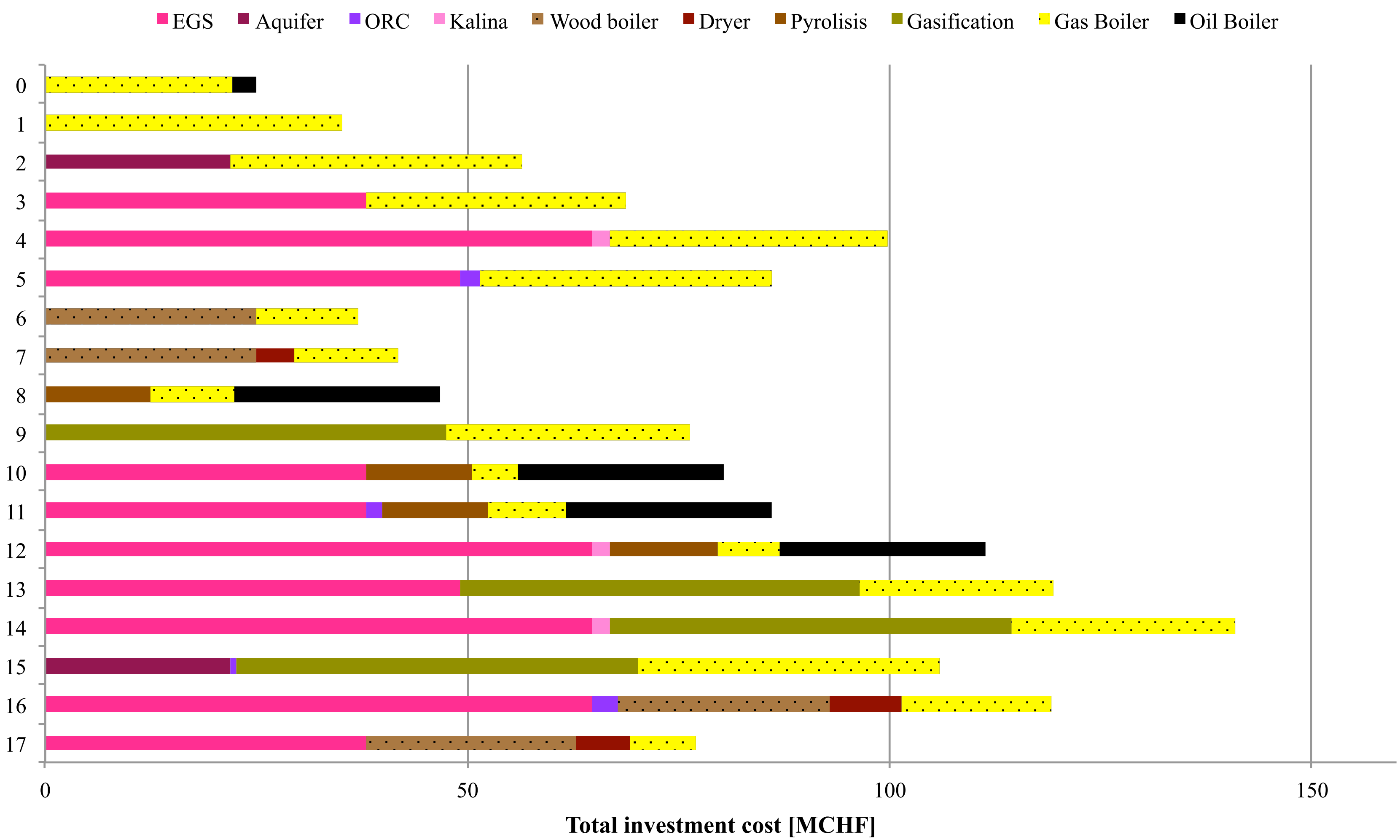
THANK YOU!

Thank you for your attention!

Questions?



APPENDIX
Investment cost breakdown



Introduction | Methodology | Models | Scenarios | Conclusions