Approaches and Strategies for Addressing Data and Research Gaps

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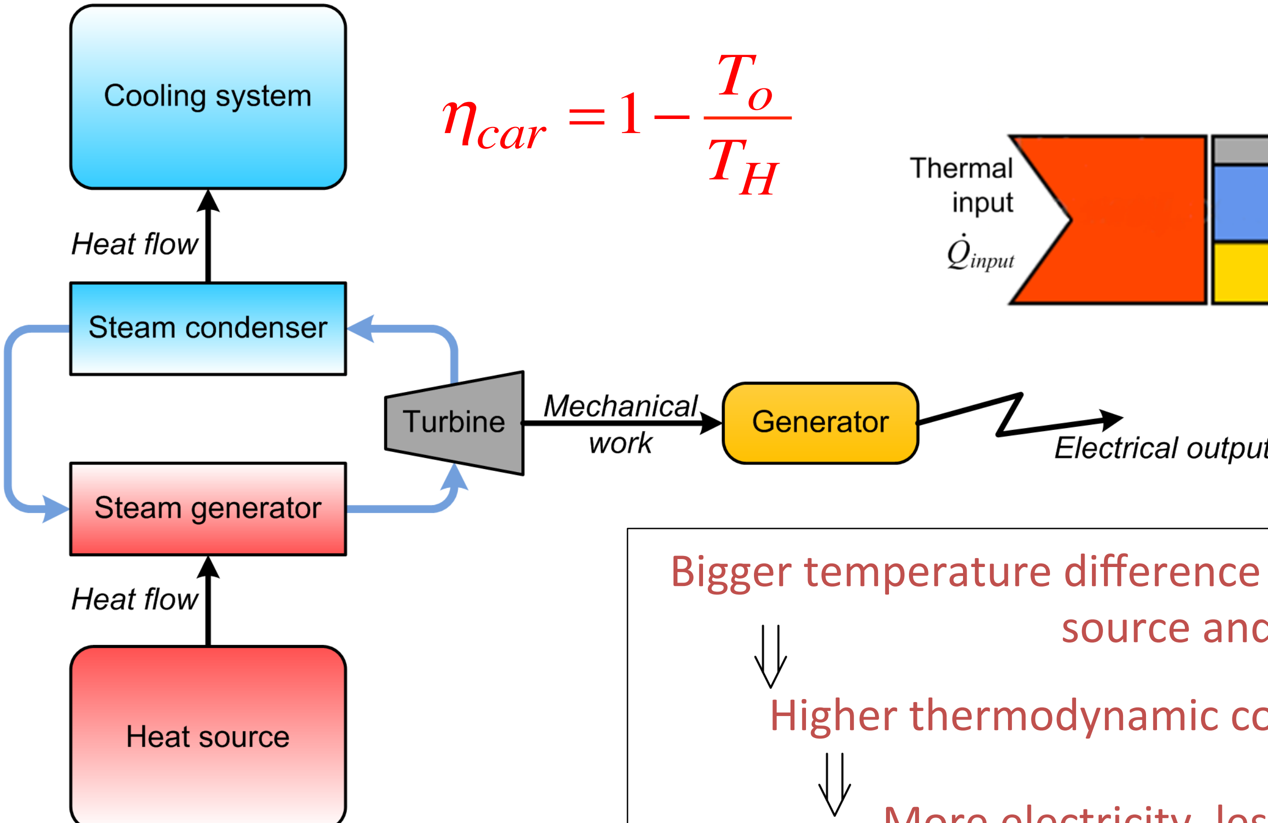
Presentation based mostly on: Rutburg, M. Delgado, A., Herzog, H., and Ghoniem, A., A system-level generic model of water use at power pants and its application to regional water use estimation, ASME 2011 IMECE, IMECE2011-63786, Nov 20122, Denver CO.

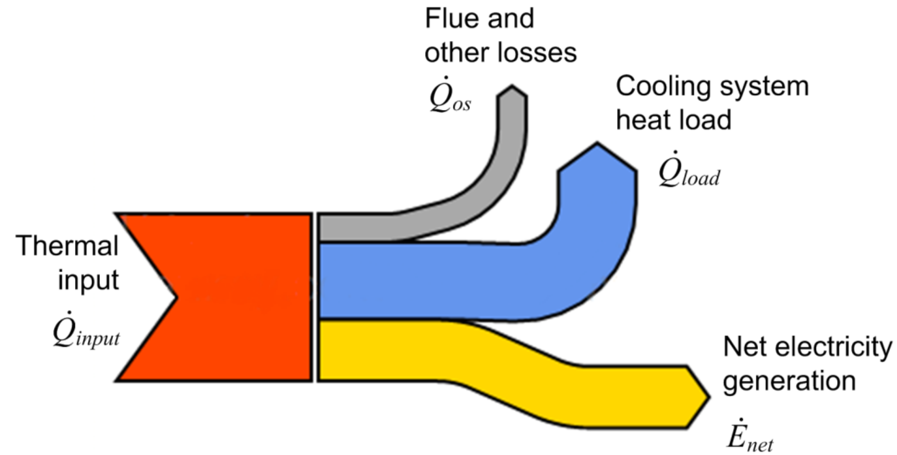
Overarching Observations:
trade-offs, regional nature & role of modeling:

- The energy-water nexus is about trade-off, between fuel, efficiency, power plant technology, and cooling technology (capital cost and LOC), CO_2, water use.
- It is regional as well as temporal, depends on weather, fuel and water availability (CO_2 is global) .. *withdrawal translates to consumption*
- Modeling: intermediate fidelity (physics based) is needed to cut through the complexity .. *for optimizing the solution and accounting for uncertainty*.
- Data for validation are needed, both coarse and fine grain, spatial and temporal, over fuel and technology.

Power plant energy balance tradeoffs



$$\eta_{car} = 1 - \frac{T_o}{T_H}$$



Bigger temperature difference between thermal energy source and sink

⇓

Higher thermodynamic conversion efficiency

⇓

More electricity, less heat to sink

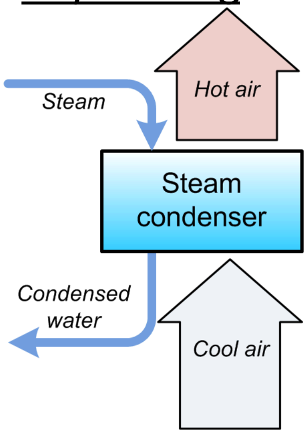
⇓

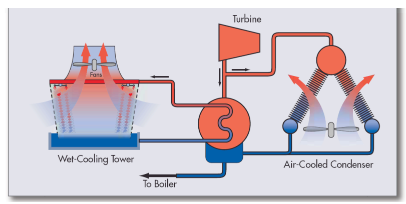
Less cooling water

Solar thermal, geothermal and nuclear *plants run at lower temperatures than combustion plants, have lower thermal efficiencies and* ***higher water footprints – but lower carbon footprints****!*

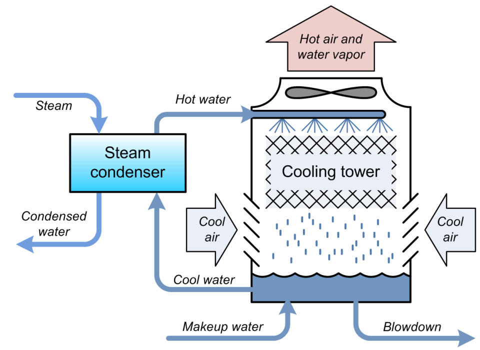
Cooling system types, use and tradeoffs

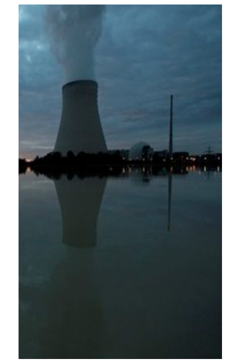
Dry cooling



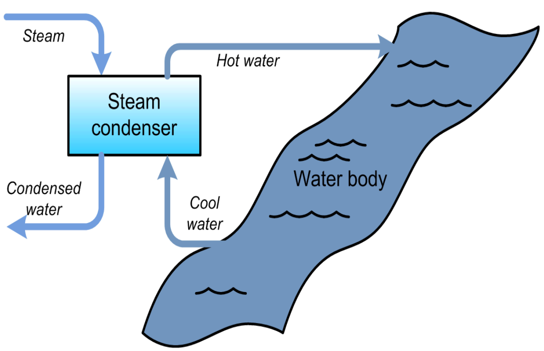


Wet tower cooling





Once-through cooling

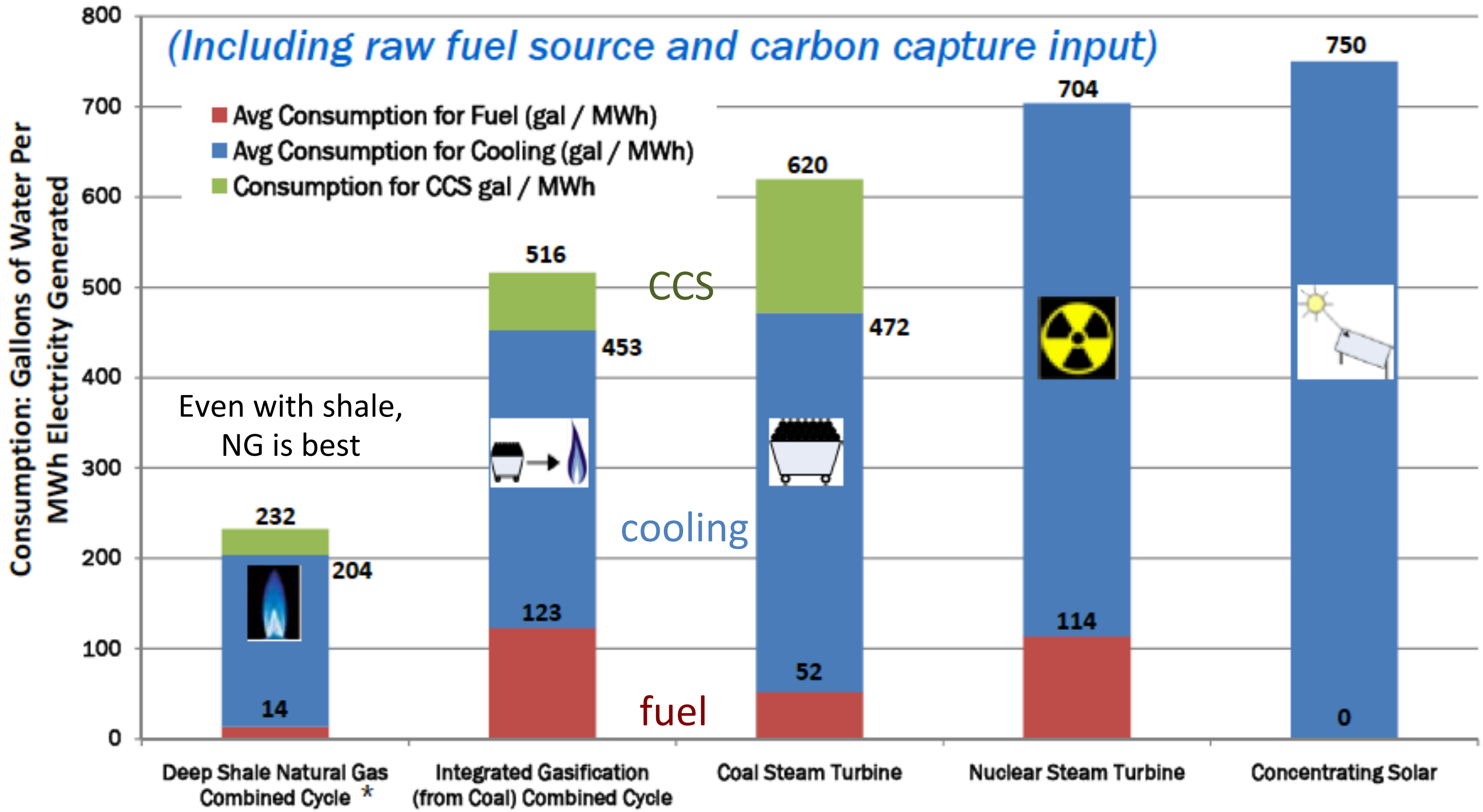


And donot forget CO_2

	H2O withdrawal	H2O consumption	Capital cost	Plant efficiency	Ecological impact
Once-through cooling:	red	orange	green	green	red
Wet tower cooling:	orange	red	orange	green	green
Dry or hybrid cooling:	green	green	red	red	green

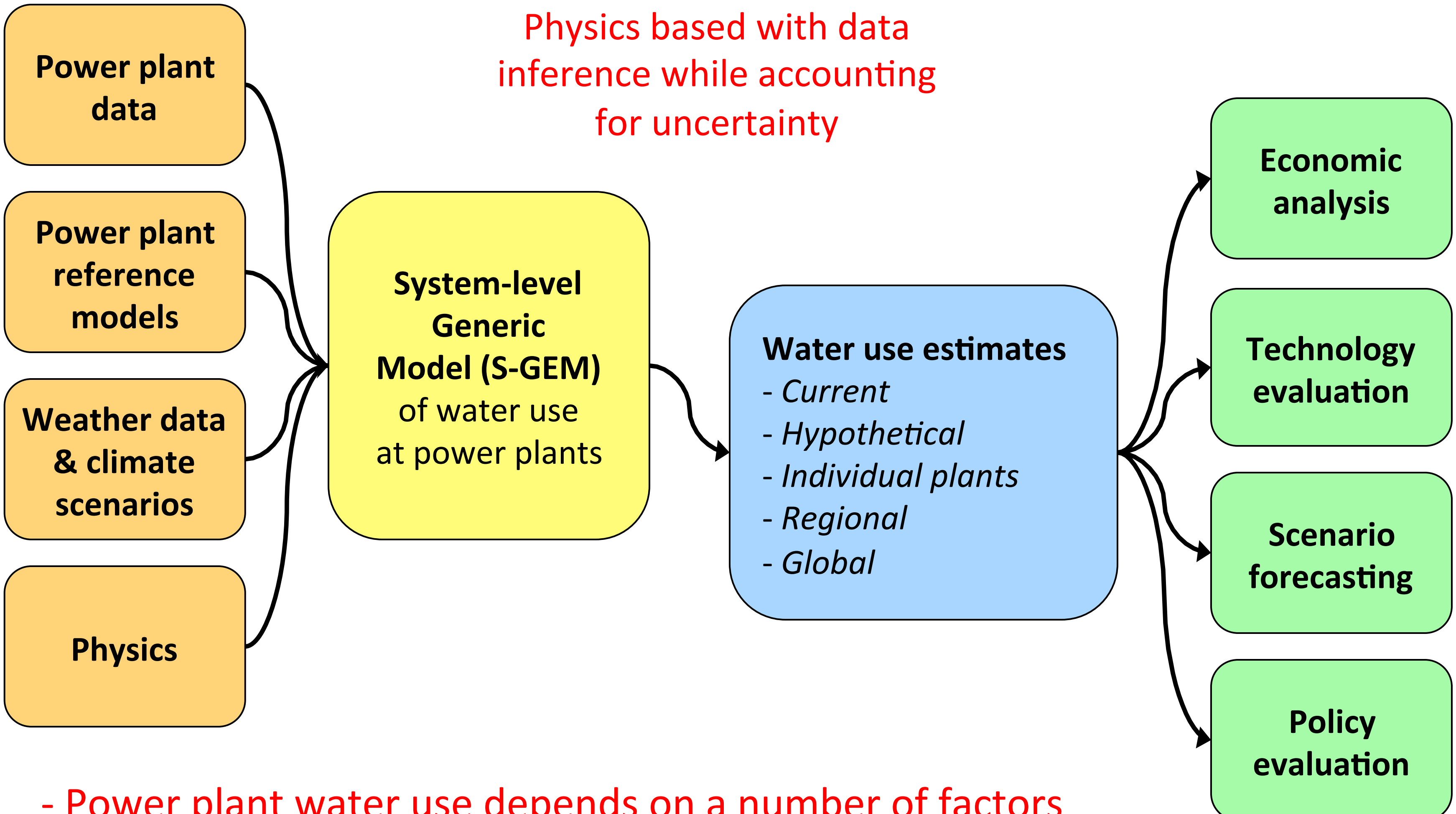
Life Cycle Consumption for Electricity Production

Water to produce fuel and for cooling. CCS is higher because of efficiency loss



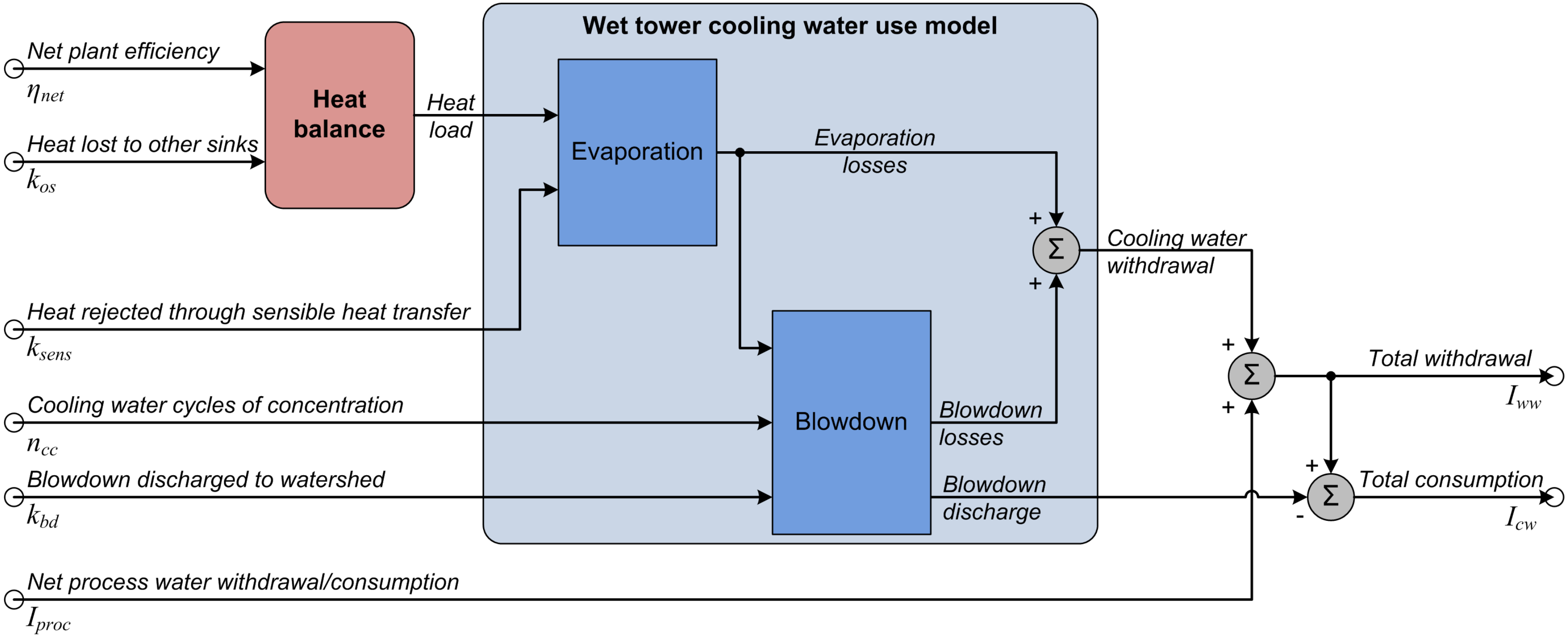
Source: USDOE 2006 (other than CHK data) and USDOE/ NETL 2007
*Average consumption for fuels; Chesapeake data
MWh = megawatt-hour

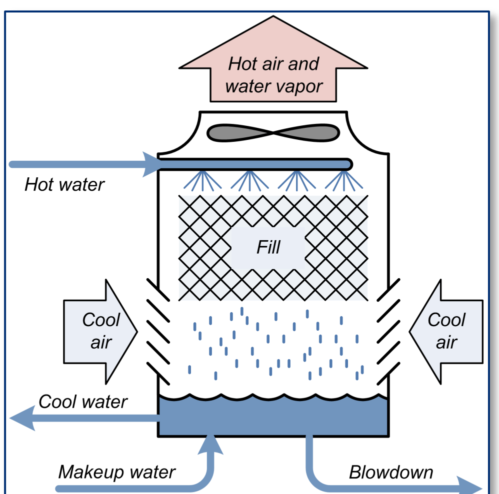
Why a system-level model of water use?



- Power plant water use depends on a number of factors
- Field data is often unavailable, unreliable, or coarse-grained
- Detailed models in the literature are not widely applicable

The model: S-GEM for wet tower cooled plant



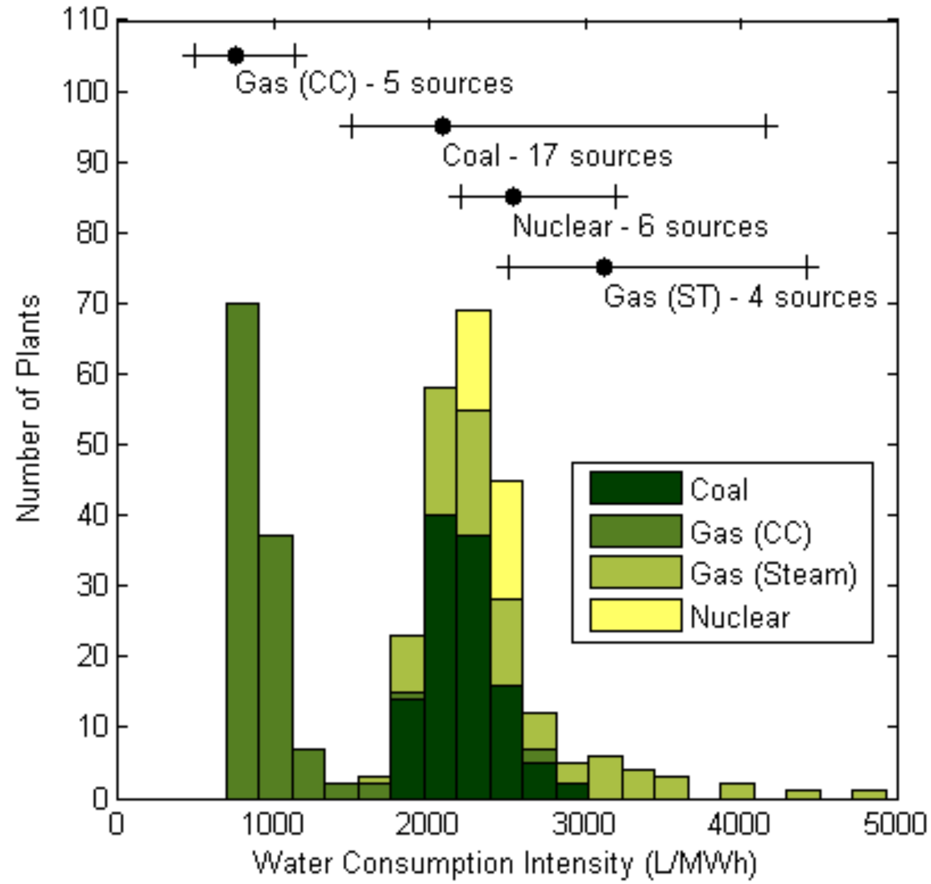


$$I_{ww} = 3600 \frac{(1-\eta_{net}-k_{os})}{\eta_{net}} \frac{(1-k_{sens})}{\rho_w h_{fg}} \left(1+\frac{1}{n_{cc}-1}\right) + I_{proc}$$

$$I_{cw} = 3600 \frac{(1-\eta_{net}-k_{os})}{\eta_{net}} \frac{(1-k_{sens})}{\rho_w h_{fg}} \left(1+\frac{1-k_{bd}}{n_{cc}-1}\right) + I_{proc}$$

S-GEM "coarse-grain validation" using water use data from literature

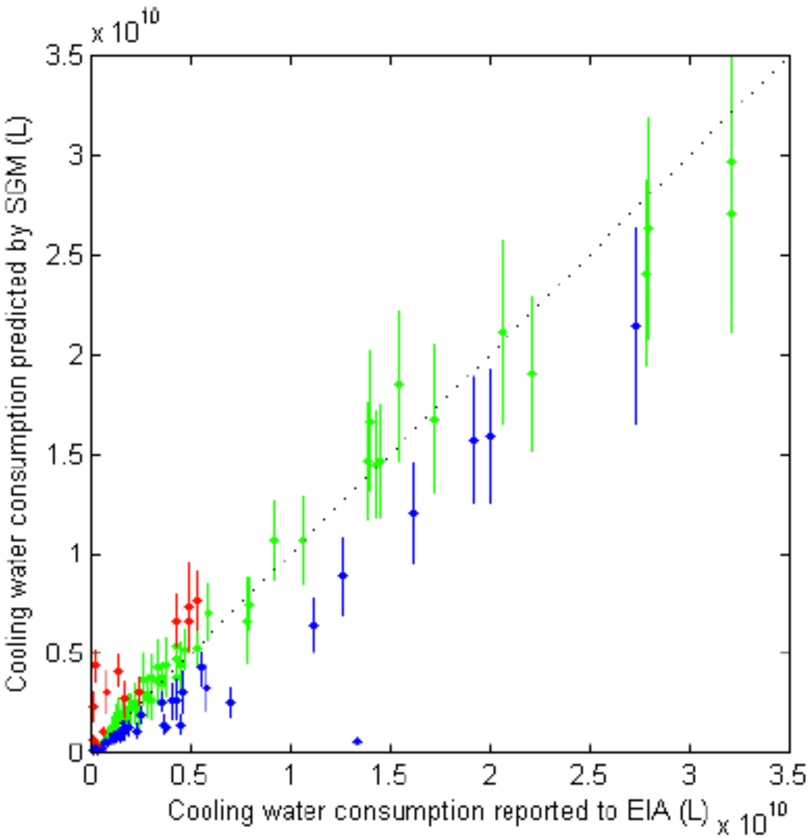
- Used S-GEM to estimate water consumption intensity for a large number of wet cooled plants in the US
  - Parameter sources:
    - η_{net}: EIA
    - k_{os}: DOE-NETL reference models
    - k_{sens}: Cooling tower models, NCDC weather data
    - I_{proc}: DOE-NETL reference models
    - k_{bd}: Neglect blowdown
- Compared results to consumption intensity values presented in a meta-study of the literature (Macknick et al, 2011)



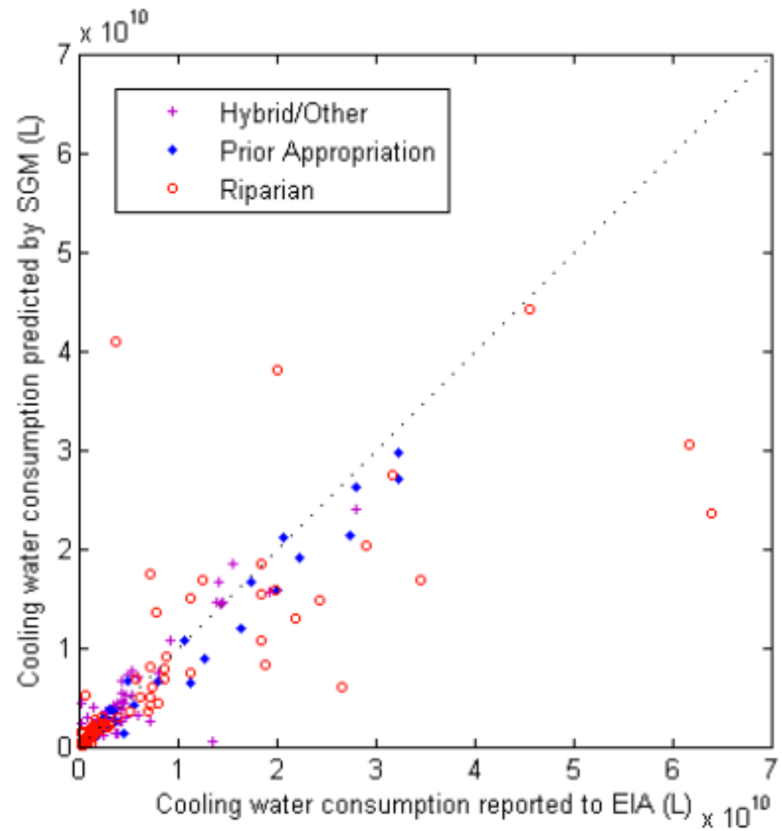
Histogram of S-GEM estimates of plant water consumption intensity with medians and ranges of values from the literature

S-GEM : Vetting field data

and what you might learn about quality of data and the source

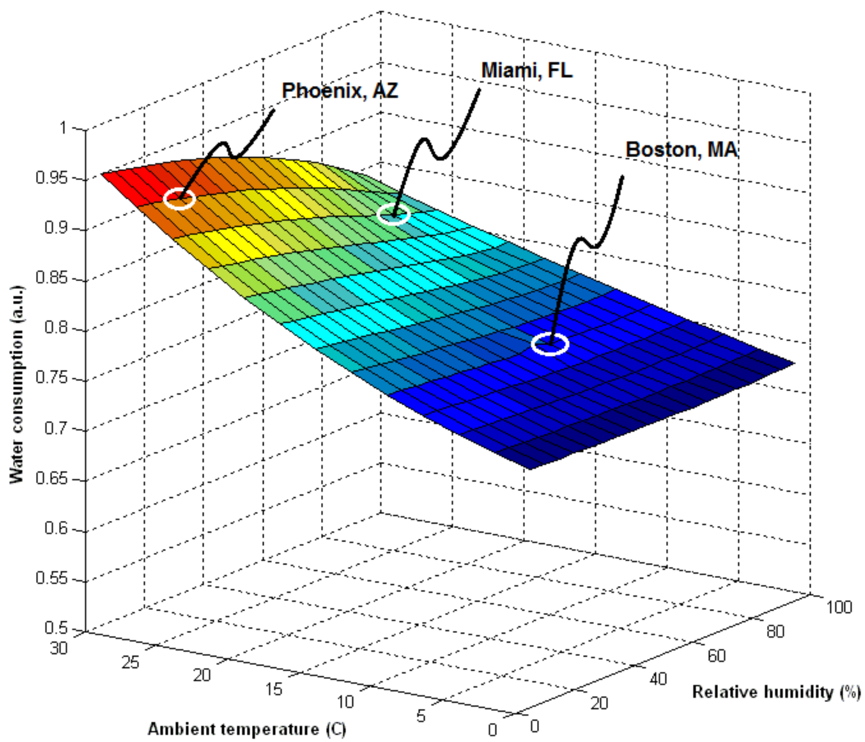


Comparison of predicted and reported water consumption (*sites in prior appropriation "western" states only*). Reported values fall within S-GEM for 53.4% of sites (green), 12.6% (red) and 34% (blue). The linear correlation was 0.96

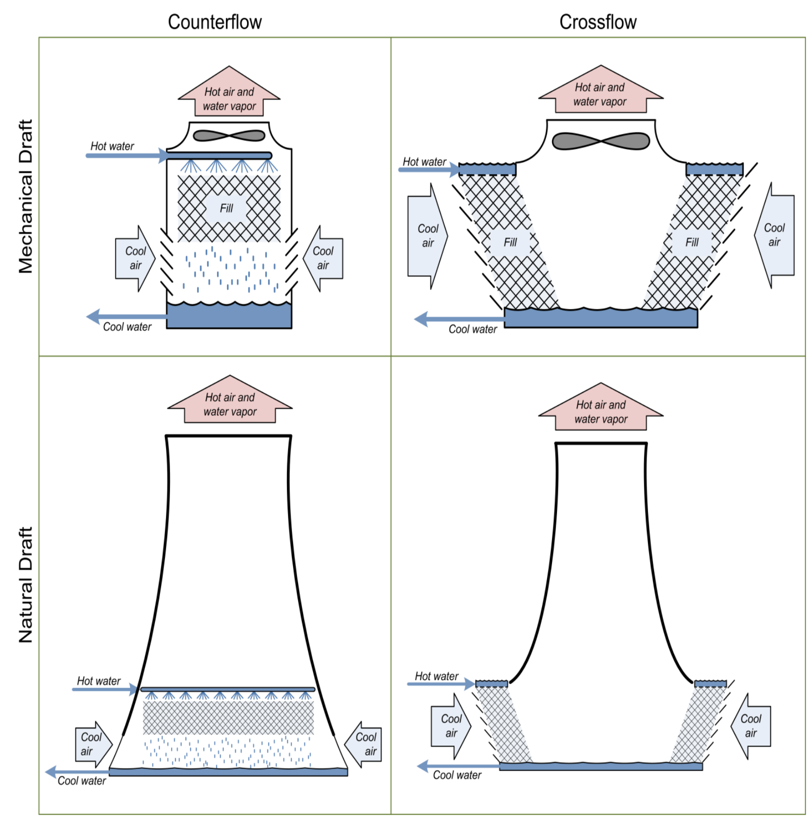


Markers indicate basis of water rights laws in US states. Roughly *Riparian law* applies where water is plentiful (eastern states) and *prior appropriation* otherwise (western). Sites with highest discrepancies are in riparian states (not carefully reported!).

Effect of environment on cooling tower consumption (and how to choose the tower technology)



The same cooling tower consumes a different amount of water depending on **where it's located** and what **time of year** or **time of day** it's operating



Cool air extracts more heat in sensible energy form. Humid air suppresses evaporation.

Finer Grain Validation plant/month analysis

Plant	Cooling system type	n_{cc}	Measured I_c (L/MWh)	Measured η_{net} (HHV)	Calculated k_{os} ($I_{proc} = 0$ L/MWh)	Calculated k_{os} ($I_{proc} = 150$ L/MWh)
Arnot	Wet tower	20	2074	32.6%	12.6%	16.6%
Duvha	Wet tower	20	2005	33.6%	11.0%	15.1%
Hendrina	Wet tower	20	2327	30.5%	12.4%	16.2%
Kendal	Indirect dry	--	136	32.7%	--	--
Kriel	Wet tower	35	2202	33.8%	3.7%	7.9%
Lethabo	Wet tower	39	1819	34.9%	12.8%	17.3%
Majuba	Hybrid	--	974	33.1%	--	--
Matimba	Direct dry	--	106	33.5%	--	--
Matla	Wet tower	14	1994	34.8%	10.3%	14.4%
Tutuka	Wet tower	39	1915	35.0%	9.4%	13.9%

Table 1: Coal-fired power plants in the Eskom data set, with median values of measured water consumption intensity, measured net efficiency, and back-calculated k_{os}

Rutburg, M., Modeling Water Use in Thermoelectric Power Plants, M.Sc. Thesis, MIT, 2012.

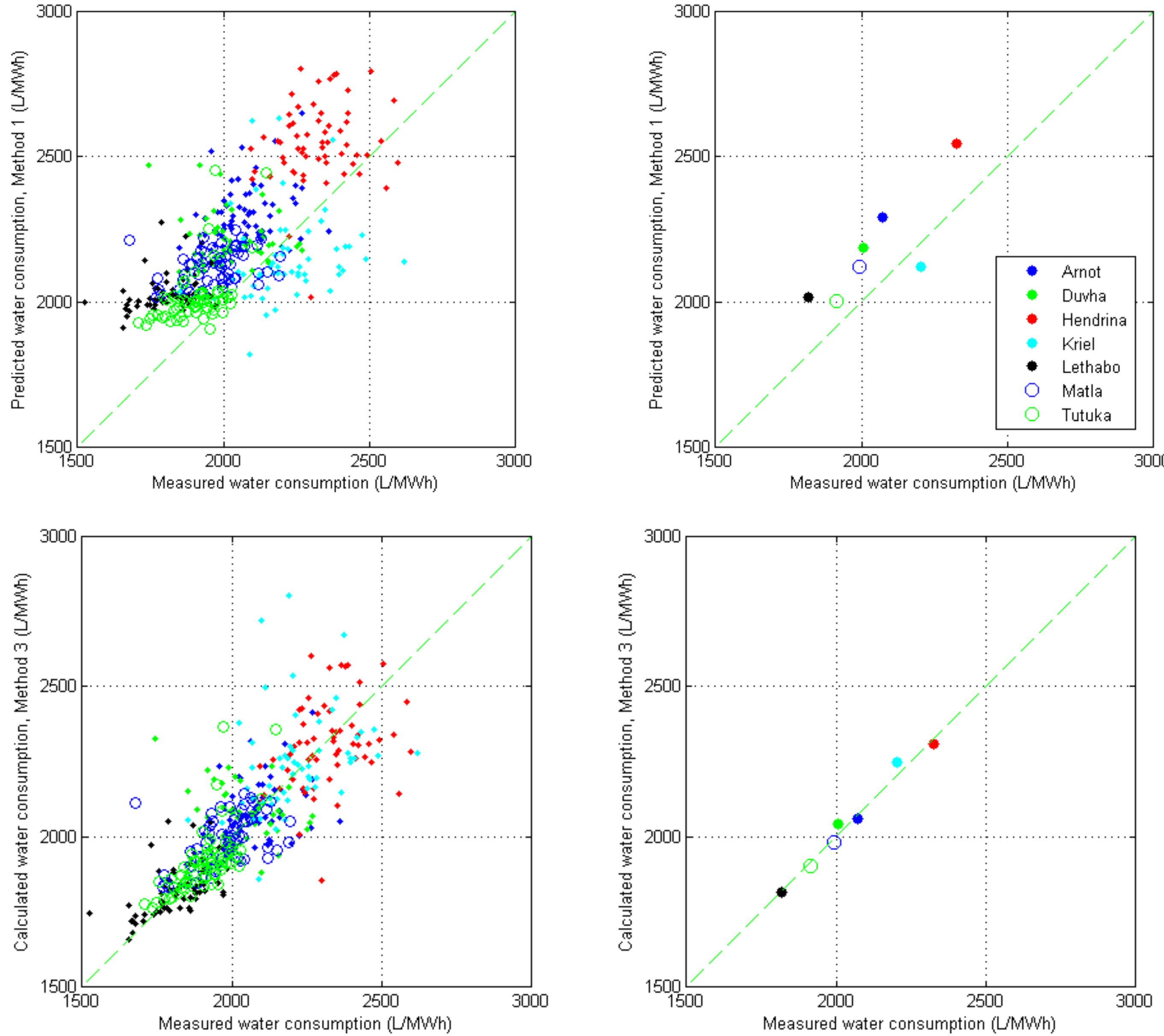


Figure 1: Accuracy of water consumption calculations using two parameter estimation methods. Individual plant-month data are shown on the left-hand charts, medians for each plant on the right-hand charts. Four outlying plant-months (3 from Kriel, 1 from Hendrina) fall outside the plotted range and are thus not shown in the left-hand charts.

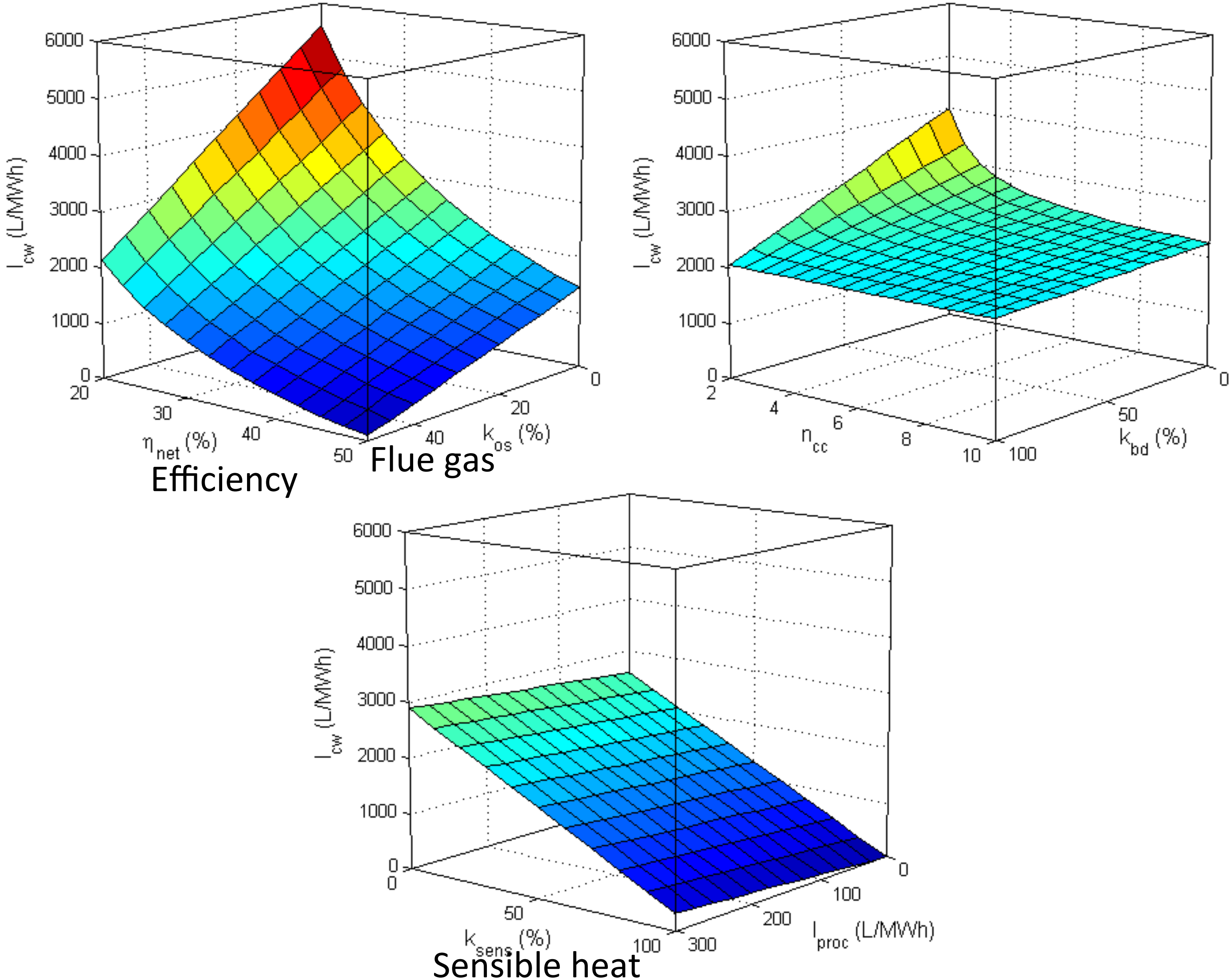


Figure 1: Bivariate sensitivity of water consumption intensity I_{cw} to (a) heat balance parameters η_{net} and k_{os}; (b) blowdown parameters n_{cc} and k_{bd}; and (c) parameters k_{sens} and I_{proc}

What we have done/learned so far (insight and sensitivity):

- formulate a coarse grained intermediate-fidelity (energy and material balance) …. validated against a sample of EIA (plant by plant) data, compared with data from NREL, further comparison with of Eskom (monthly, coal, plant by plant zero discharge data). …
- Model can be used as a quality assurance tool for received data, design tool, policy and economic assessment tool, etc.
- Largest contributors for consumption: plant technology and source of thermal energy, cooling technologies, other uses such as desulfurization, cleaning up mirrors, etc.
- Define opportunities to reduce water: CHP, fuel switching, raising plant efficiency, aggressive application of hybrid and dry cooling, recycling of locally used water, use of lower quality water .. *revisit the trade off*.

Research Opportunities;
Modeling, Data and Technology:

- Multiscale physics-based models accounting for the local conditions (space and time), introduce economics in the models to understand the trade offs .. adding optimization tools, accounting for uncertainty. An overall framework to address the challenges.
- Exercising and refining the models.
- Fine-grained data (plant by plant, location, time and plant technology) all the way from monthly to day-to-day. *Remote collection and compilation of data*
- Water purification technologies microbial fuel cells, centrifuges, forward osmosis .. Electrochemical, reverse osmosis, advanced membranes … adsorbents, electrocoagulation, steam stripping .. .