WATER-ENERGY-CARBON NEXUS IN WATER RECLAMATION, REUSE, AND WASTEWATER TREATMENT:
2. Energy Dynamics

Diego Rosso

Associate Professor
Civil and Environmental Engineering
Chemical Engineering and Material Science

Director
Water-Energy Nexus Center

University of California, Irvine, CA (USA)

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Research at the Water-Energy Nexus

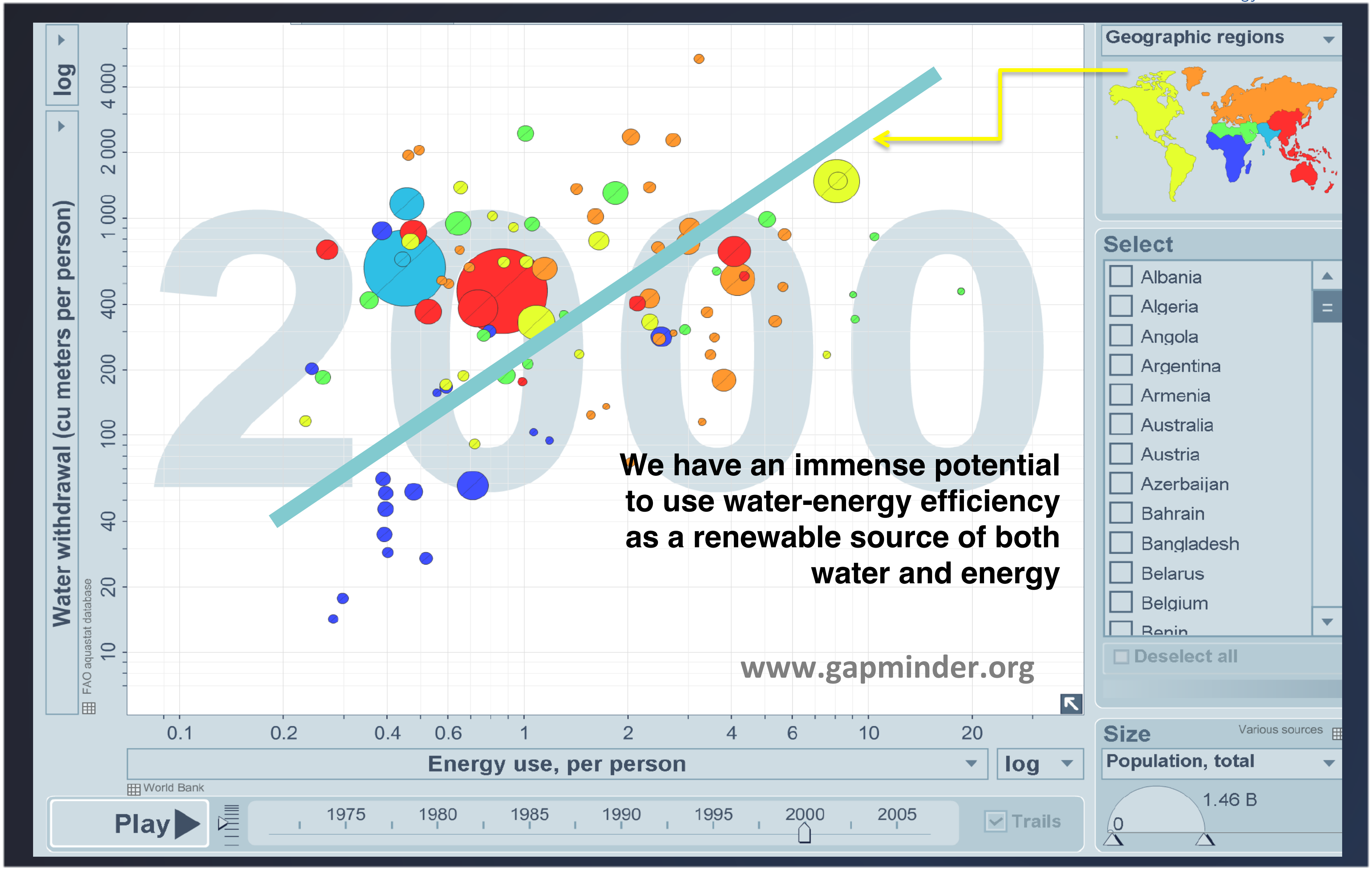
RATIONALE

Water is energy, and vice versa

- In the U.S. 40% of water is used for power generation, so the power used for water has already water in it
- e.g., 1kWh of coal power (=one 40W light bulb for 1d) requires 25 gallons of water; then when we use that kWh for water pumping or treatment the nexus closes

Source: http://www.epa.gov/watersense/water_efficiency/how_we_use_water.html

On top of the world



We have an immense potential to use water-energy efficiency as a renewable source of both water and energy

ENERGY MODELING

Information and Improvement

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Rosso et al (2012) Wat. Practice Technol.

$$eFP_{TOT} = \sum_{i=1}^{n} eFP_i = \sum_{i=1}^{n}\sum_{j=1}^{m} \underbrace{n_j}_{\text{\#units}} \cdot \underbrace{p_j}_{\text{power}} \cdot \underbrace{\eta_j}_{\text{efficiency}} \cdot \underbrace{t_j}_{\text{time in operation}}$$

Information Available	Modelling Nature	Difficulty to Gather	Margin for Improvement	Data Availability
Power bill	Cumulative	Easy	Small	Very common
Power by unit	Static	Moderate	Moderate	Rare
Power by Time-of-use (TOU)	Dynamic	Difficult	Large	Very rare

Step 1: Energy Benchmarking

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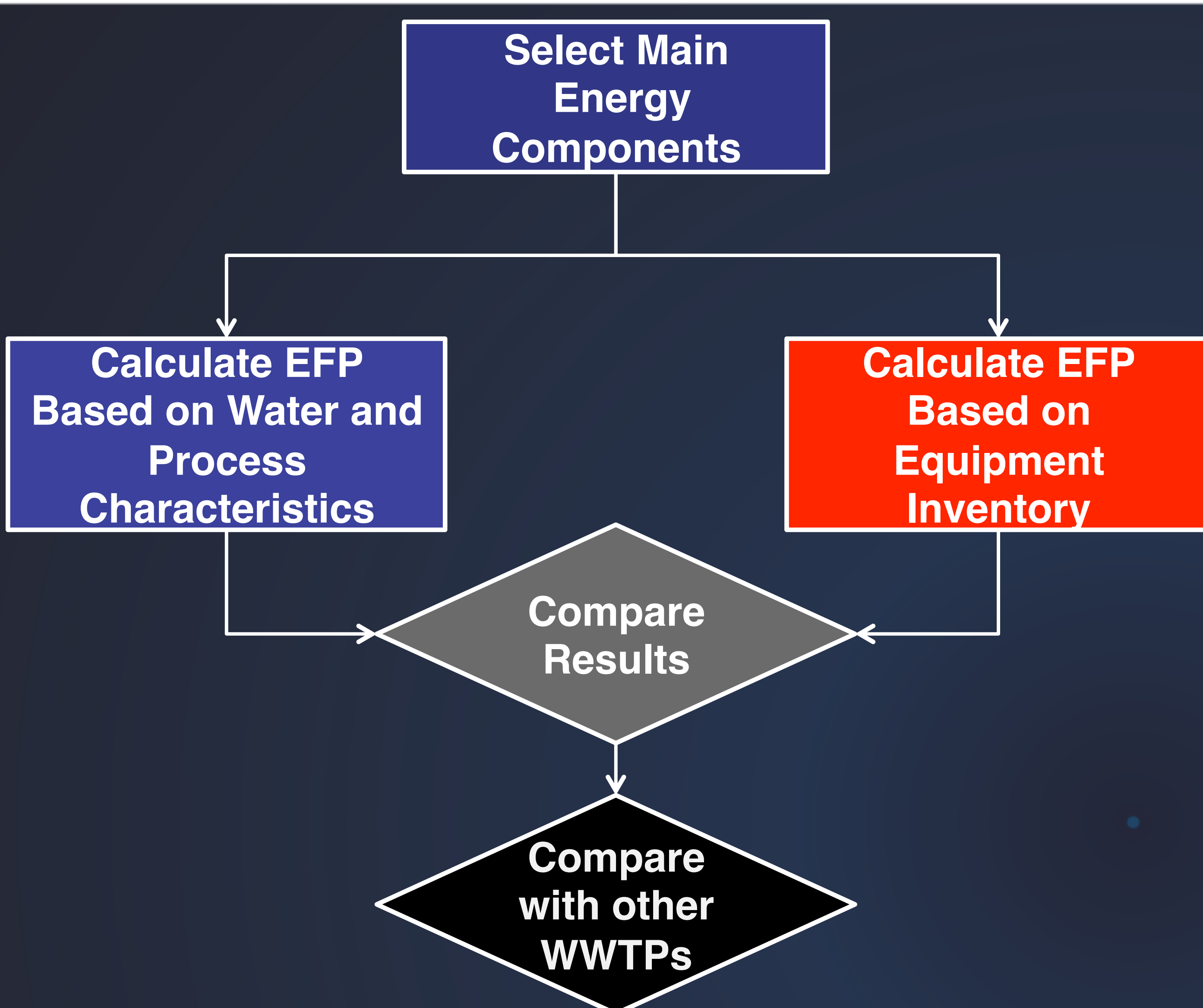
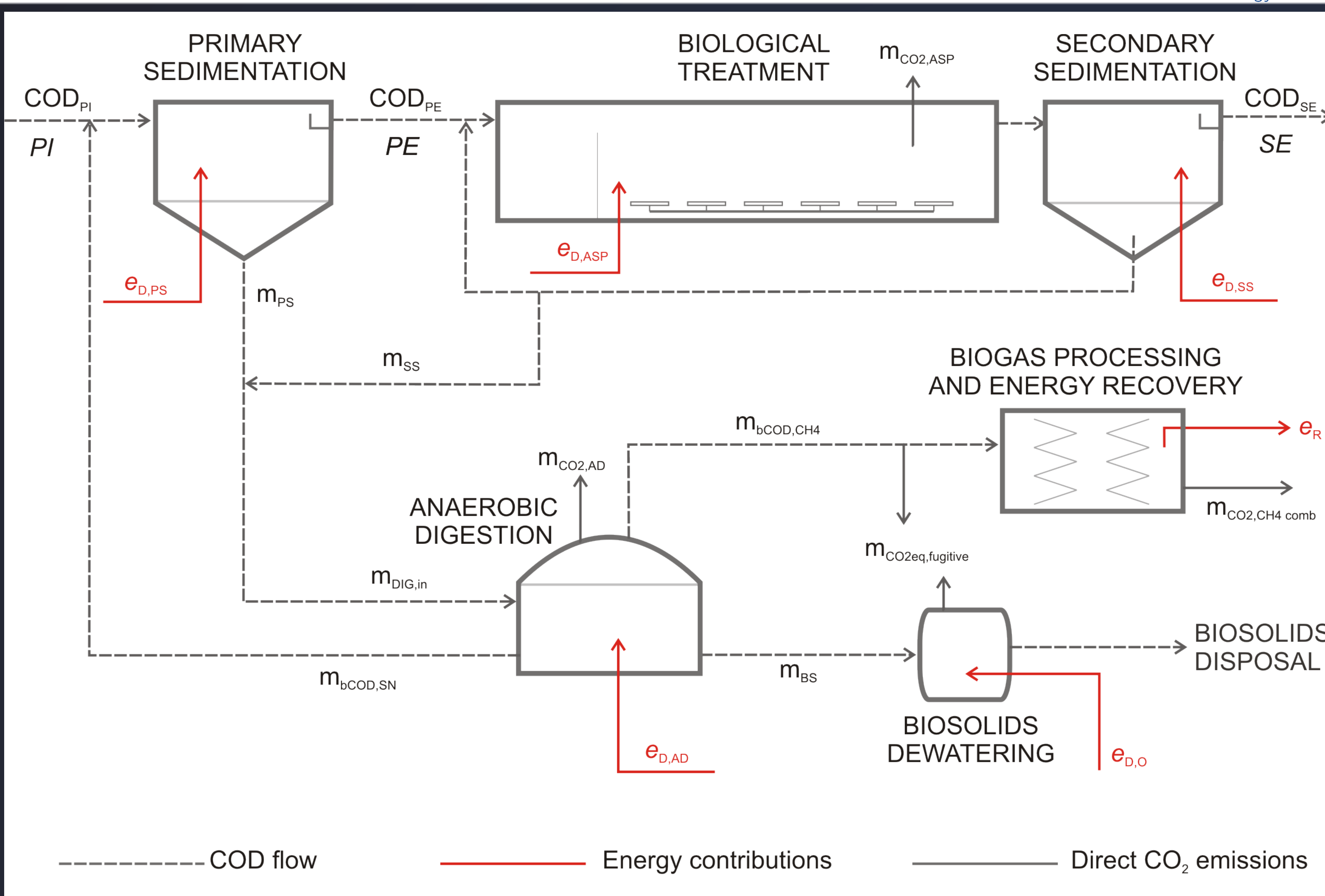


PROCESS FLOWS



PROCESS ENERGY BALANCE

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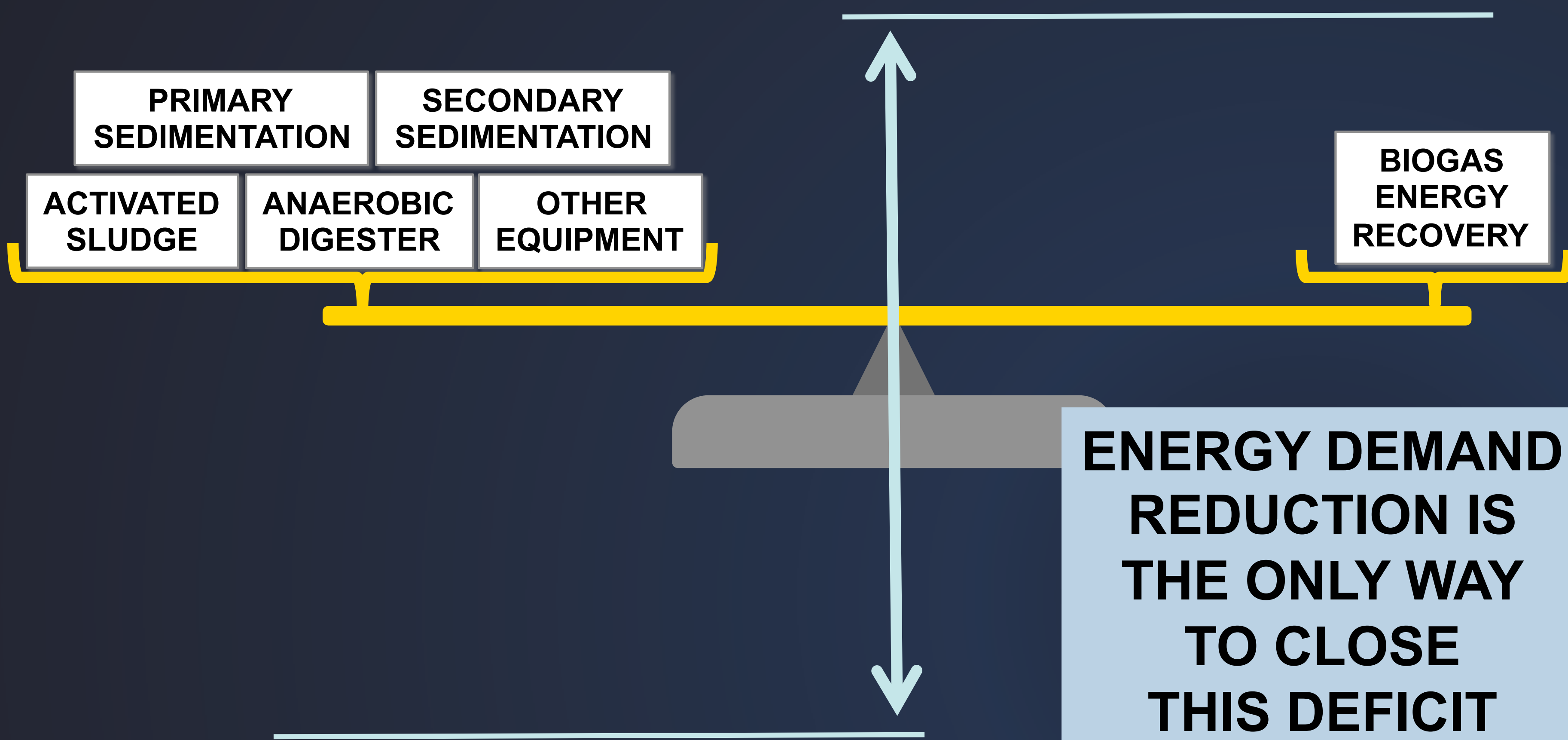

ENERGY DEMAND REDUCTION IS THE ONLY WAY TO CLOSE THIS DEFICIT

Mining Energy from Wastewater

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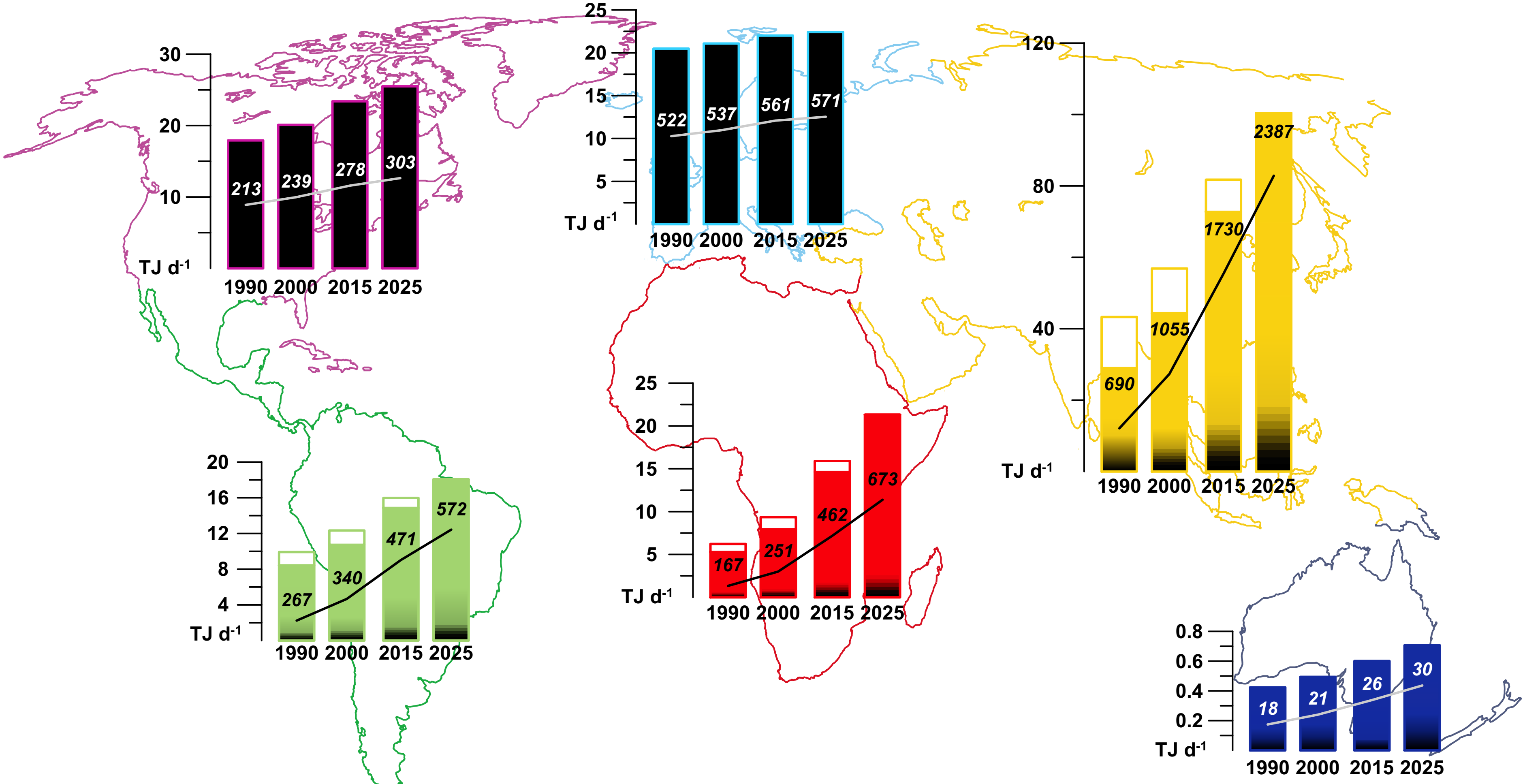

Potential for energy recovery from municipal wastewater
Rosso and Stenstrom (2008) *Chemosphere* 70 1468-1475

Case Study:
Energy vs. Product Water Quality

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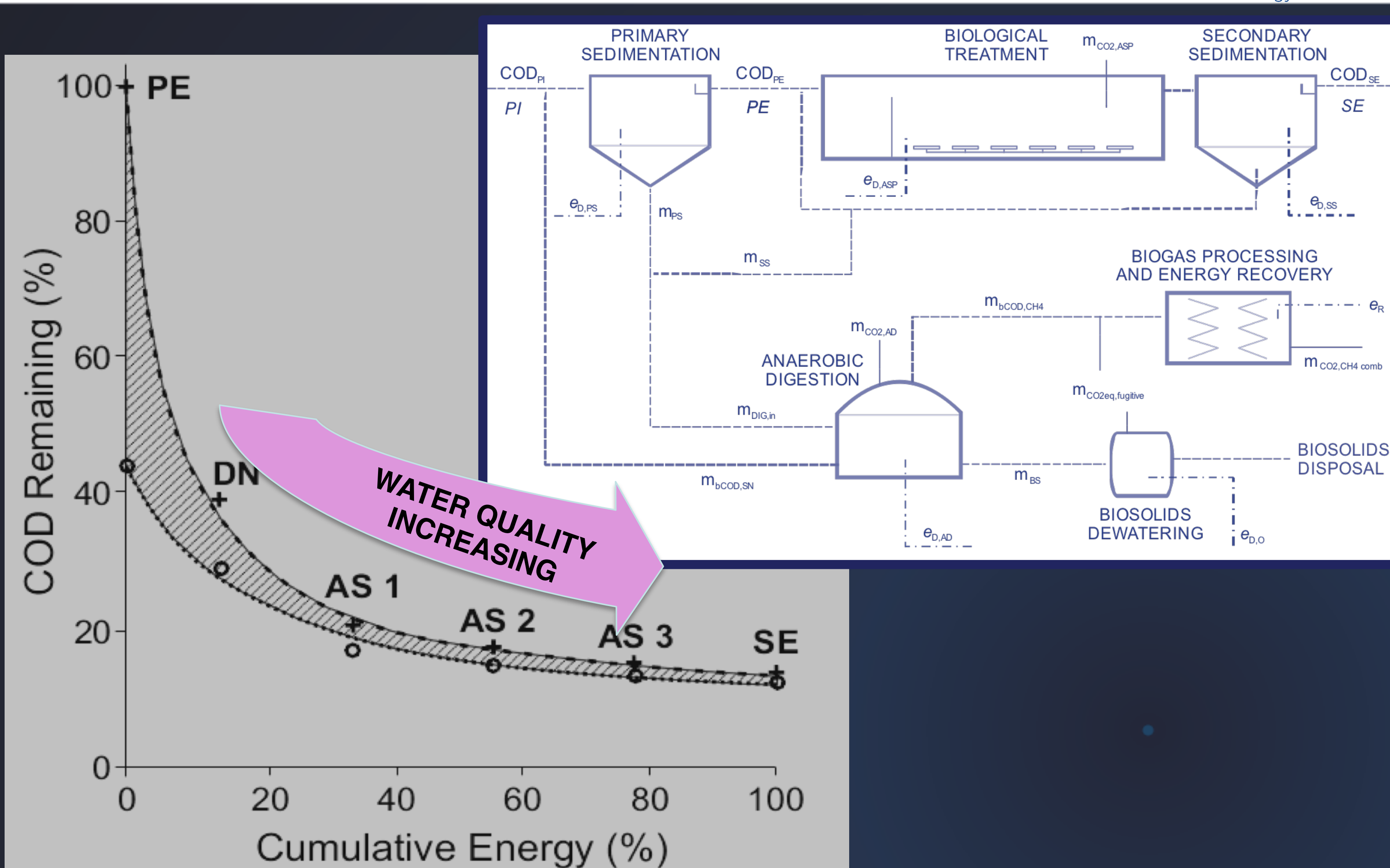

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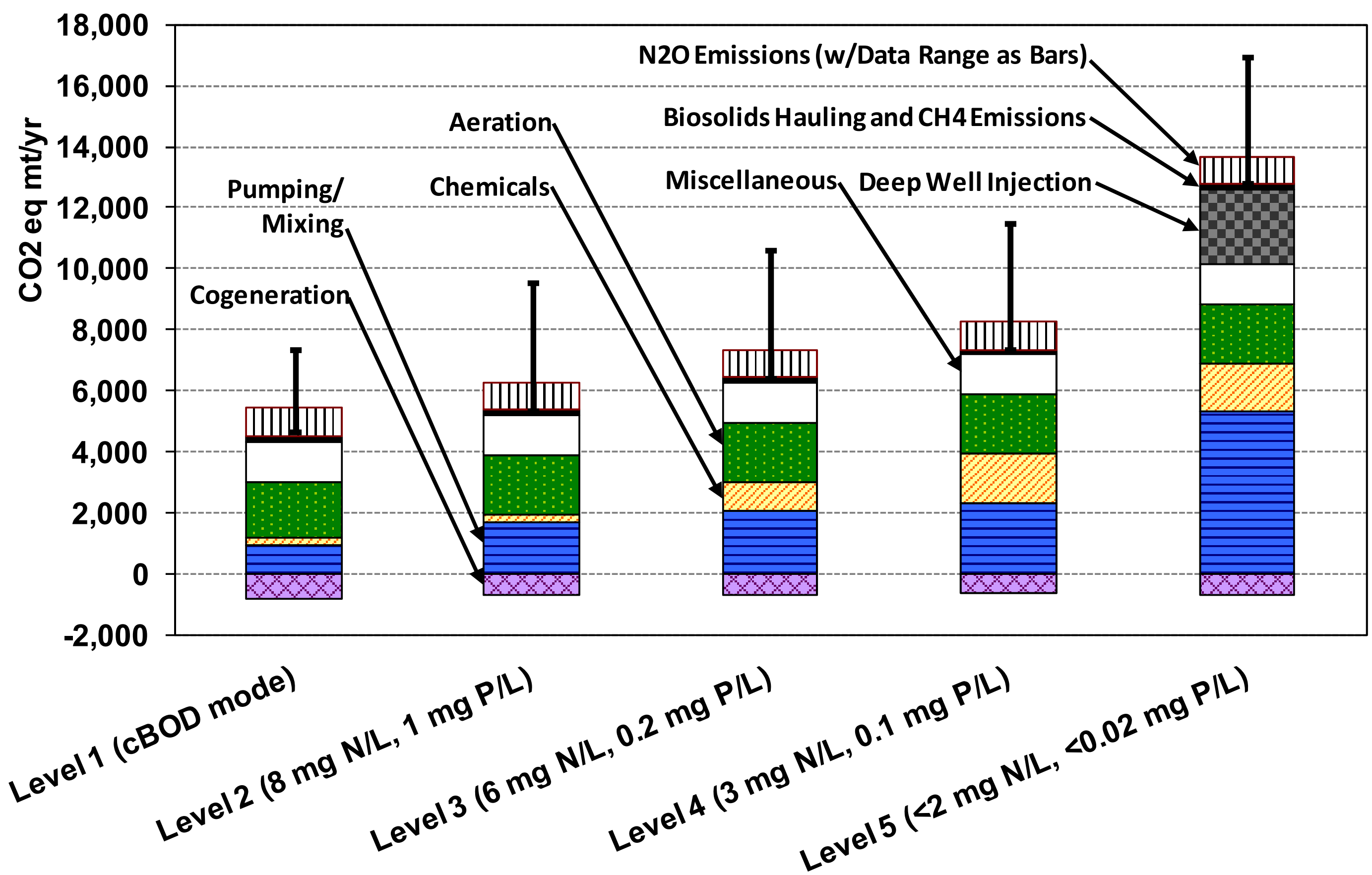

Neethling et al (2011) Proc. WEFTEC

Water-Energy-Efficiency
Case study on maximum water recovery

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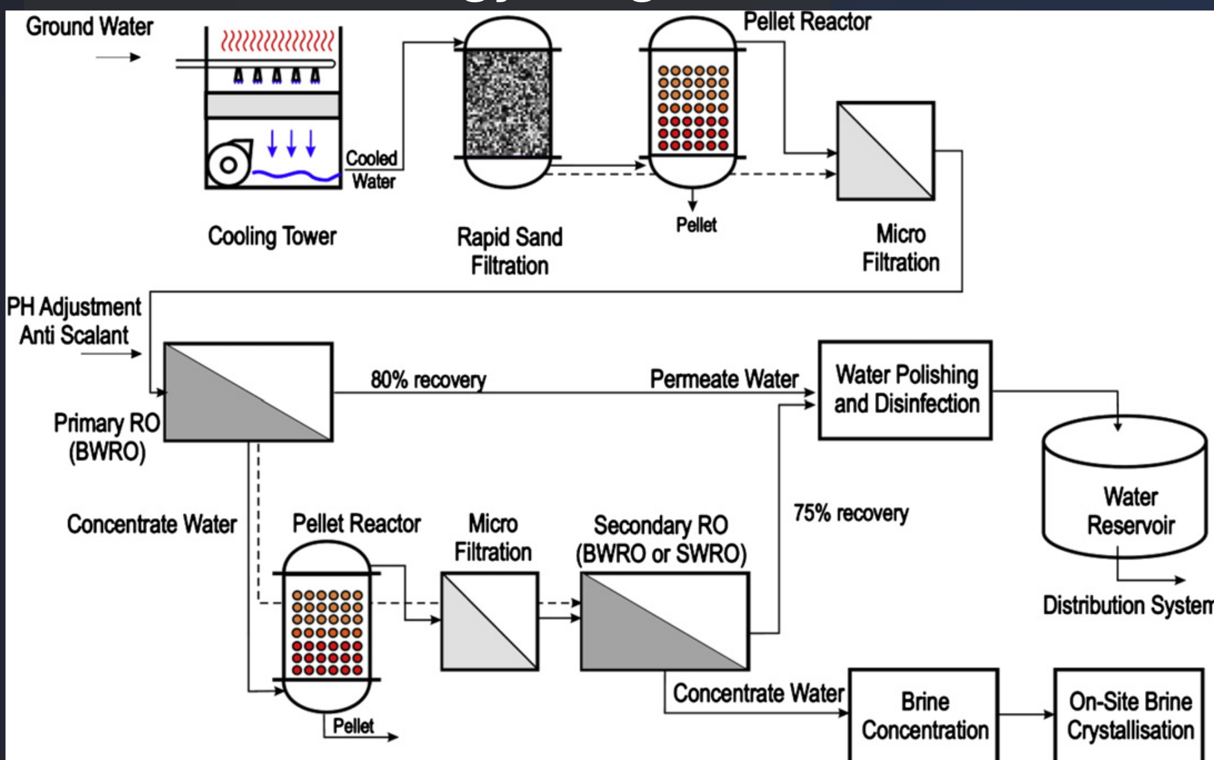
Sobhani et al (2012) *Desalination* 291 106-116

- 99% water recovery
- Zero Liquid Discharge (from waste to commodity)
- Current 40MGD pilot in construction
- Minimum energy usage



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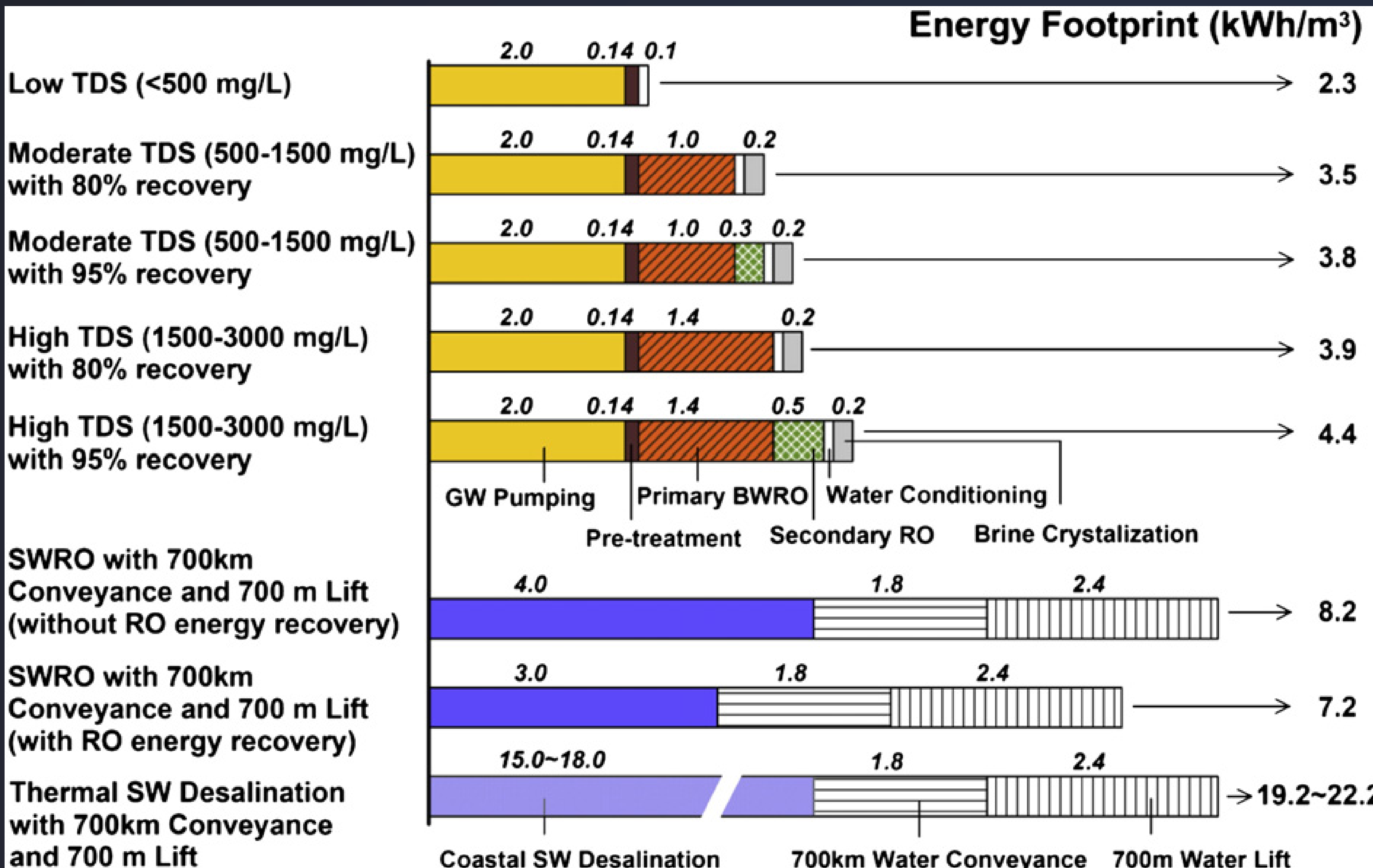

Importance of energy dynamics:
Costs and Carbon Footprint

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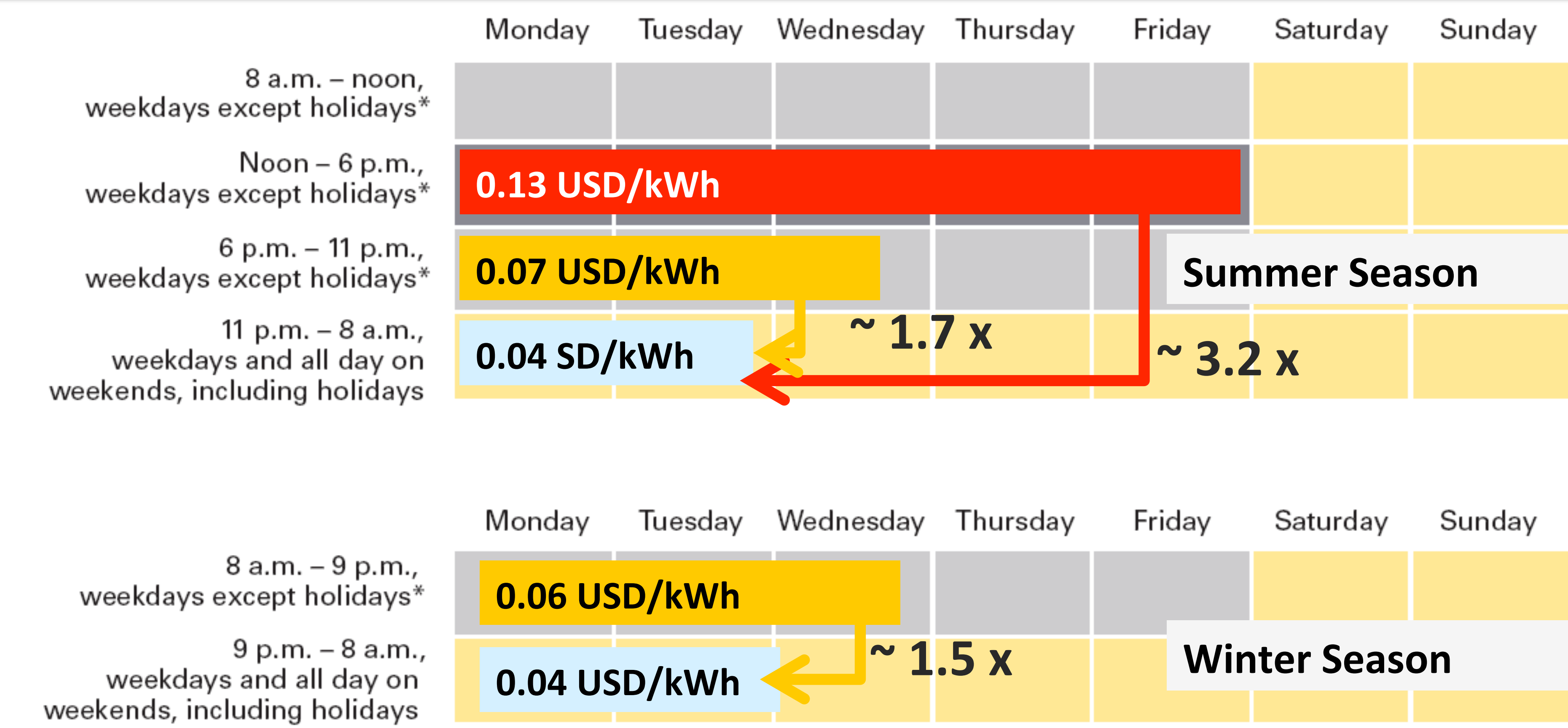

Don't forget the power demand charges!

On-Peak: Highest Energy Charge | Mid-Peak: Medium Energy Charge | Off-Peak: Lower Energy Charge

Time of Use (TOU-8) rate schedule

SOUTHERN CALIFORNIA EDISON
An EDISON INTERNATIONAL® Company

Carbon Output Rate (kg_{CO2} / kWh)

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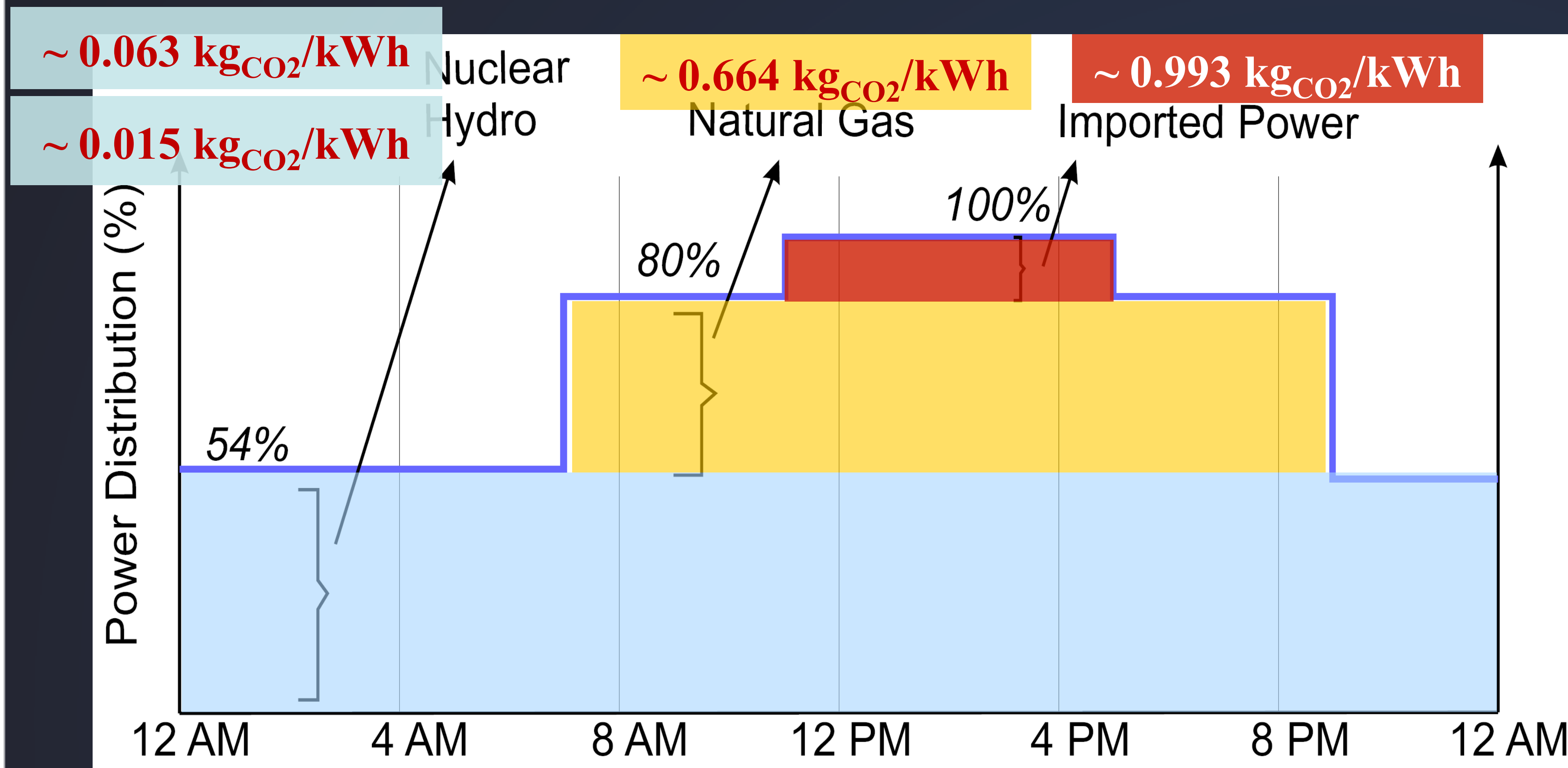

Diurnal power distribution in the State of California and related power sources (SCE, 2010)

Case Study:
Energy Usage in Water Reuse

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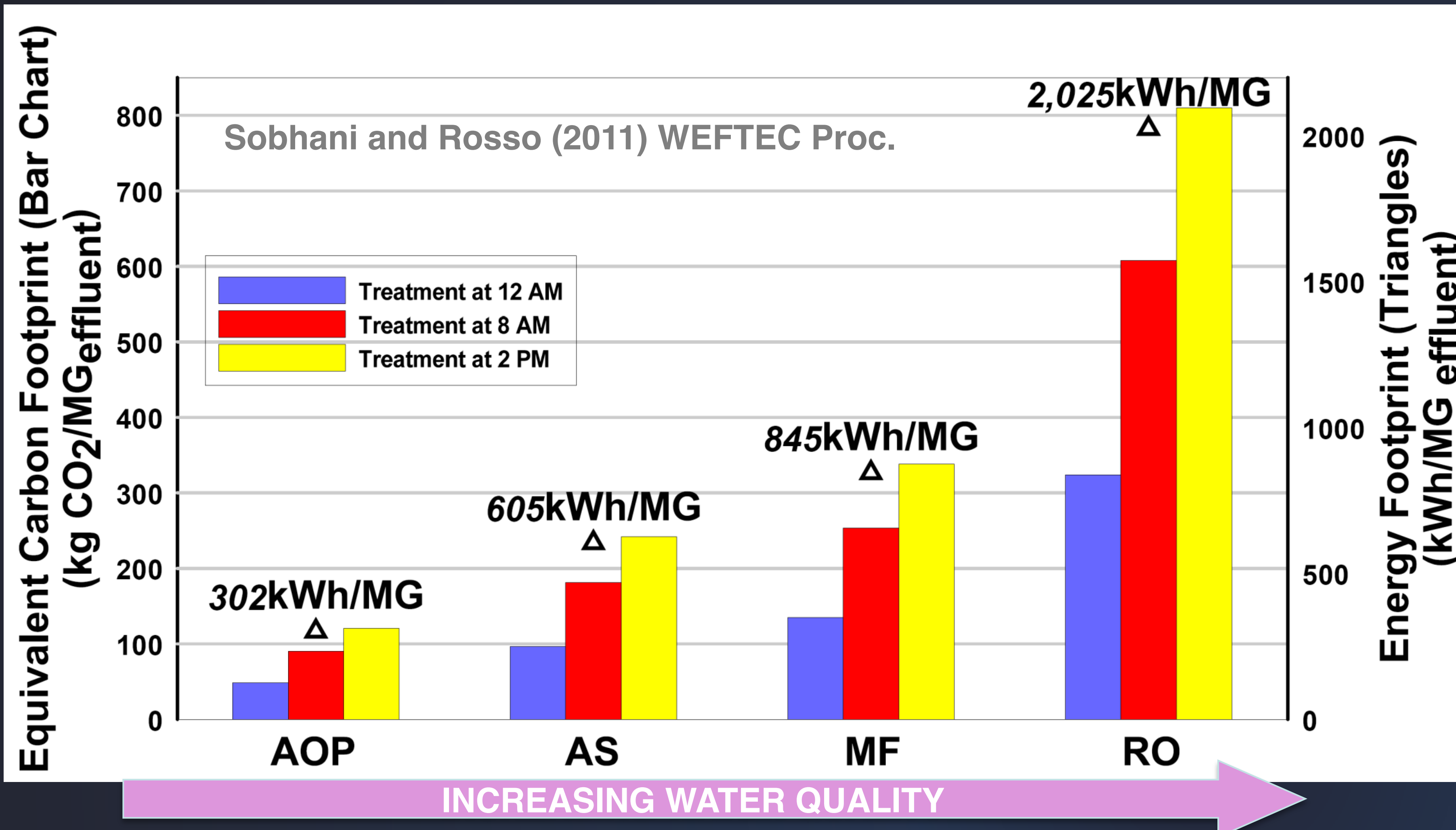

Water Reuse is a crucial component of the current and future water portfolio and more energy-efficient technology can enhance its applicability

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AERATION MODELING AND ENERGY FOOTPRINT ANALYSIS

AERATION & ENERGY FOOTPRINT

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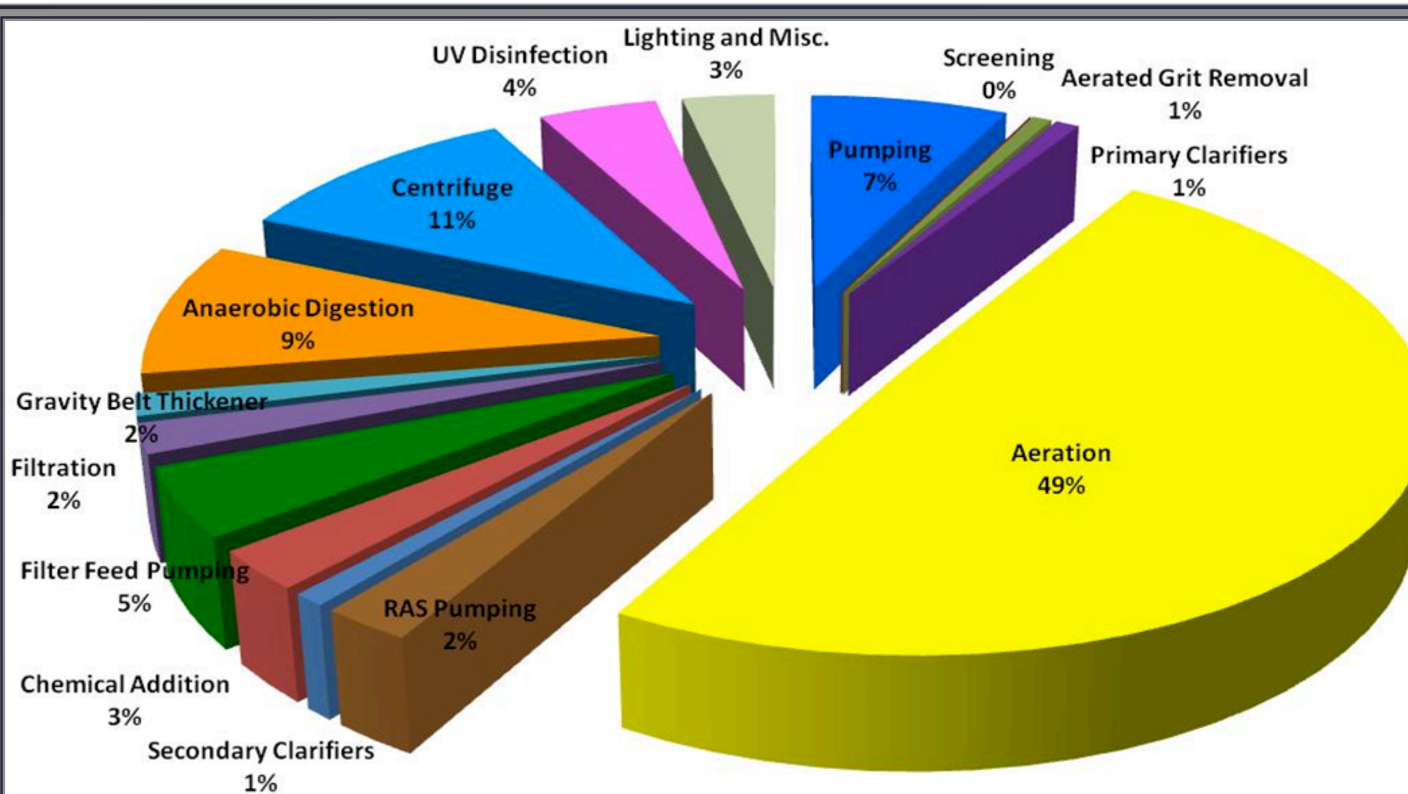

Figure 1. Estimated power usage for a typical 20MGD activated sludge facility performing wastewater treatment with nitrogen removal in the United States (MOP32, 2009).

Aeration cost = 45-75% of plant energy (w/o influent/effluent pumping)

Rosso and Stenstrom (2005) *Wat. Res.* 39: 3773-3780

Aeration Efficiency over time

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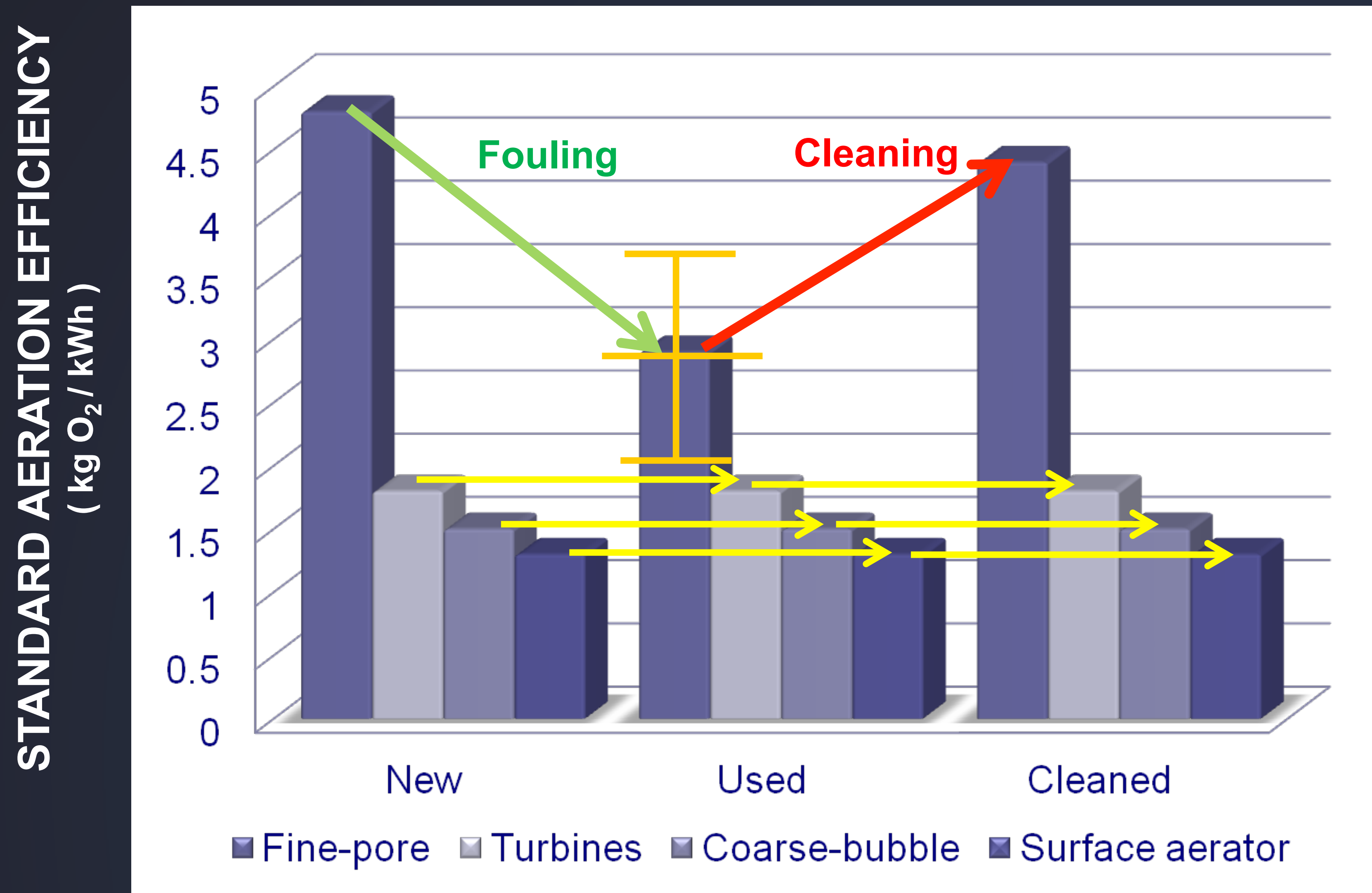

After Stenstrom and Rosso (2008)

BLOWER POWER

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$$BHP_{blower} \sim (\text{Air Flow, Pressure Drop}^{0.283})$$

Automated Off-Gas Monitoring

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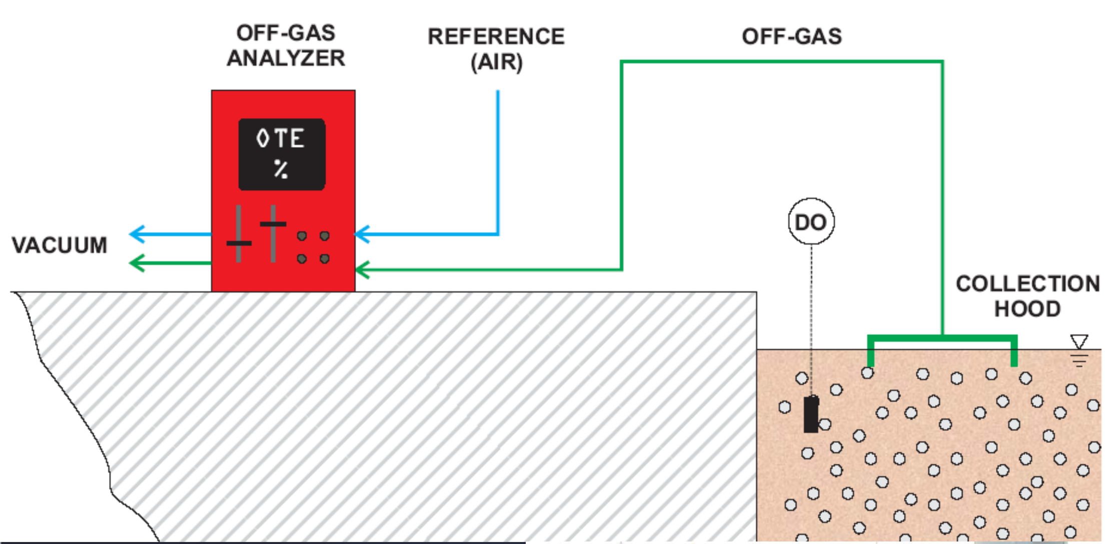
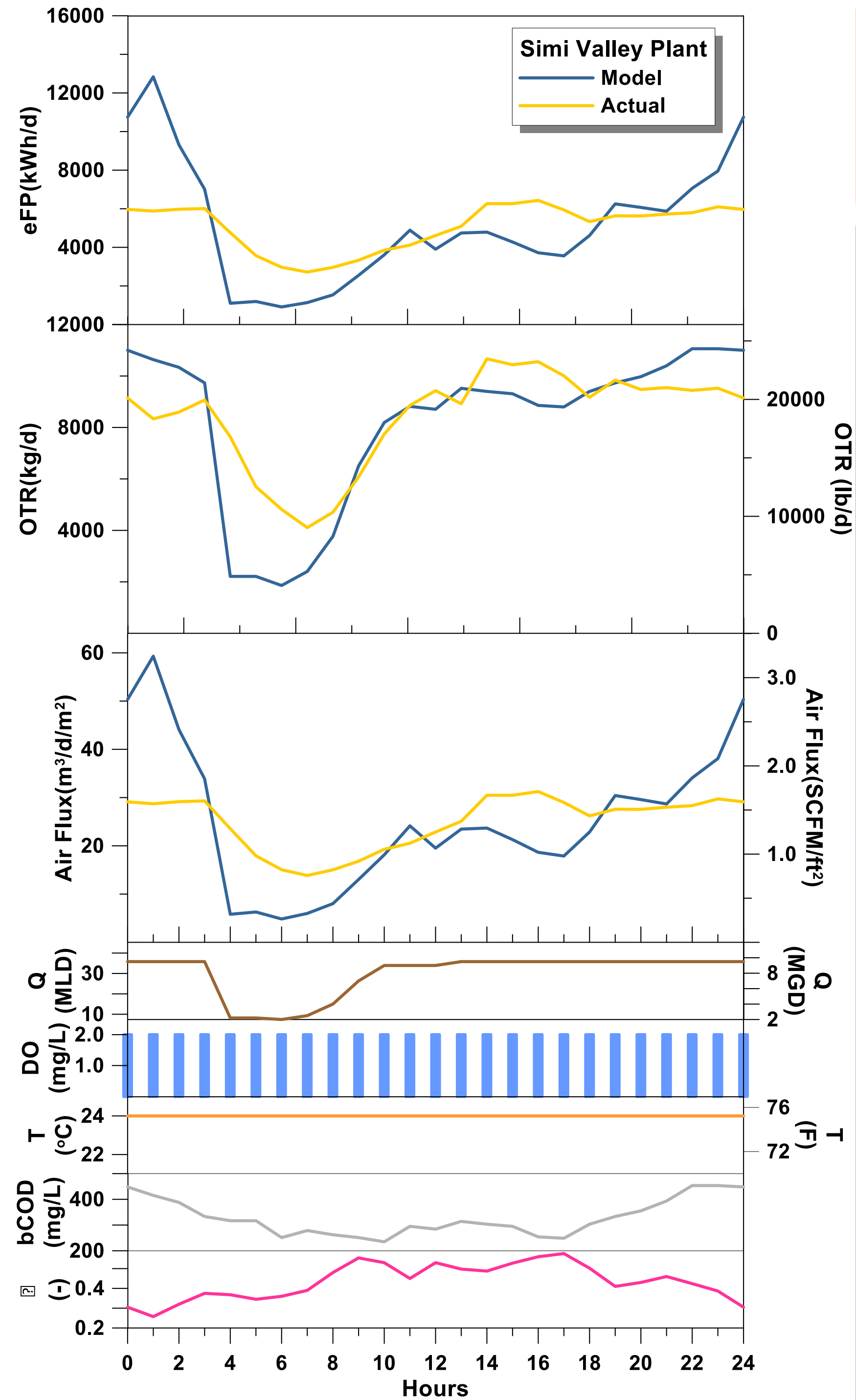


- Oxygen transfer efficiency (OTE, %)
  - Measured once per hour comparing reference air to off-gas
- Off-gas flux and temperature

- Maintenance frequency (2 weeks) to replace media and collect data (4-20 mA signal)

Simi Valley Plant

24h dynamic energy analysis



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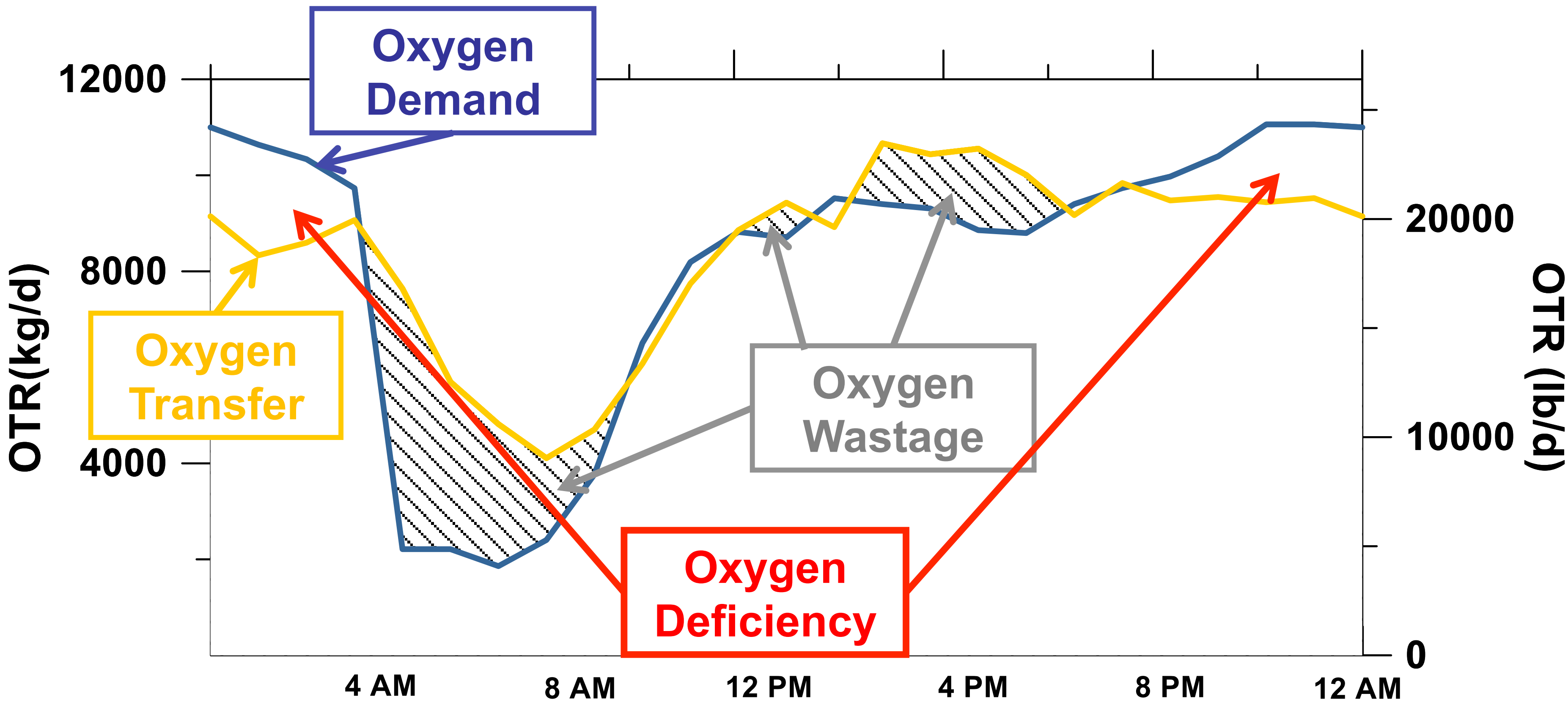
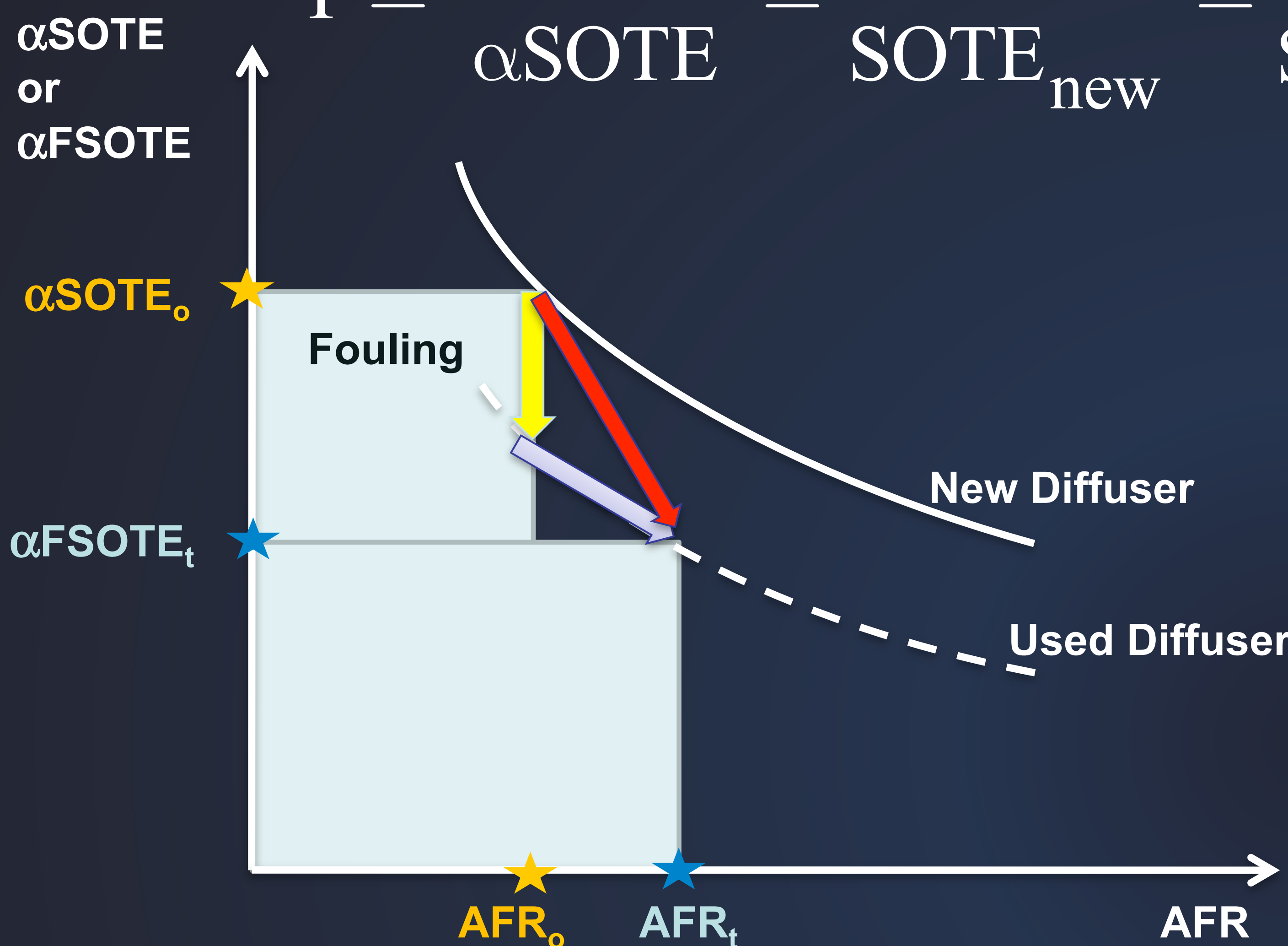


DYNAMIC ENERGY ANALYSIS IDENTIFIES DEFICIENCIES AND MARGINS FOR IMPROVEMENT

Fouling Factor

$$F=\frac{\alpha FSOTE}{\alpha SOTE}=\frac{SOTE_{used}}{SOTE_{new}}=\frac{SOTE(t)}{SOTE(0)}$$



Pressure Factor

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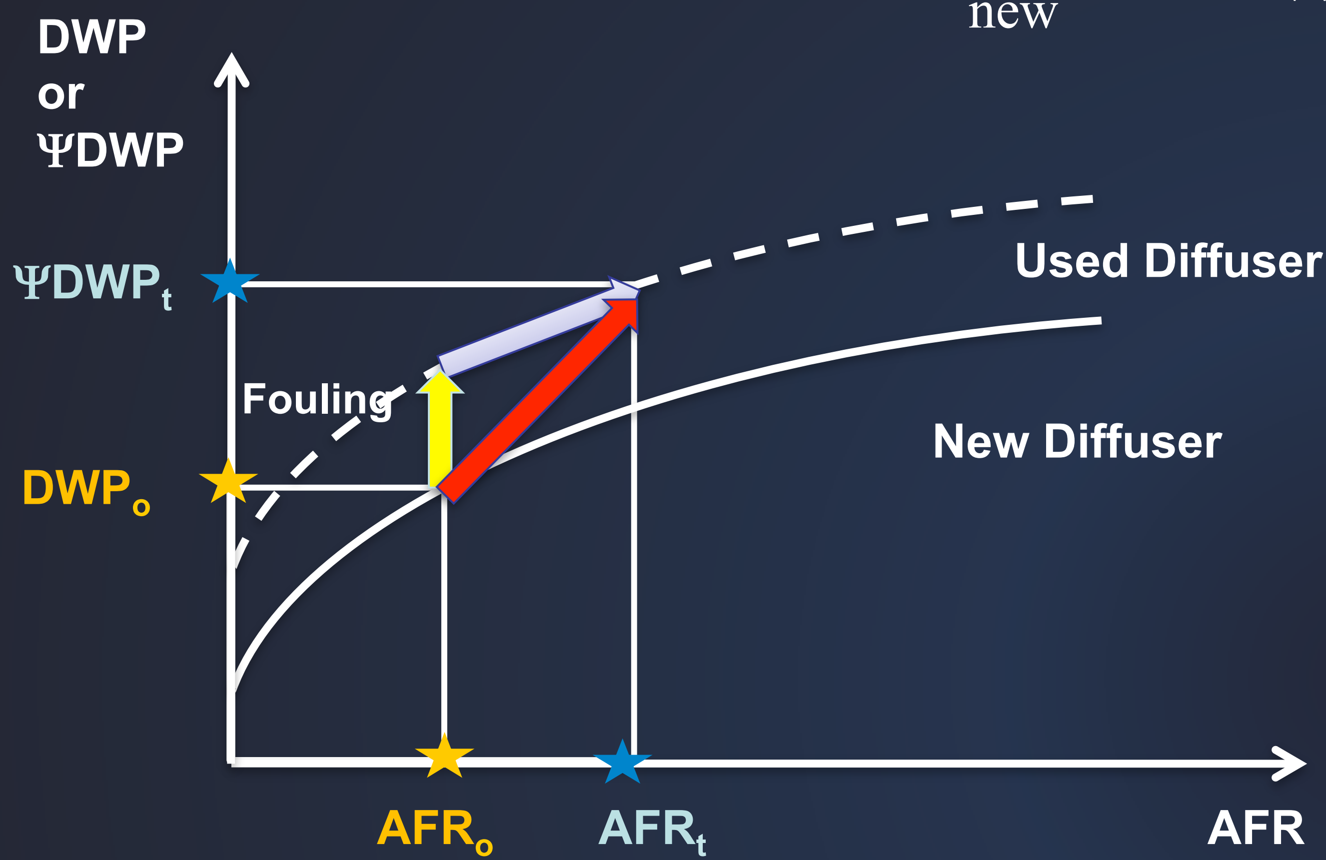
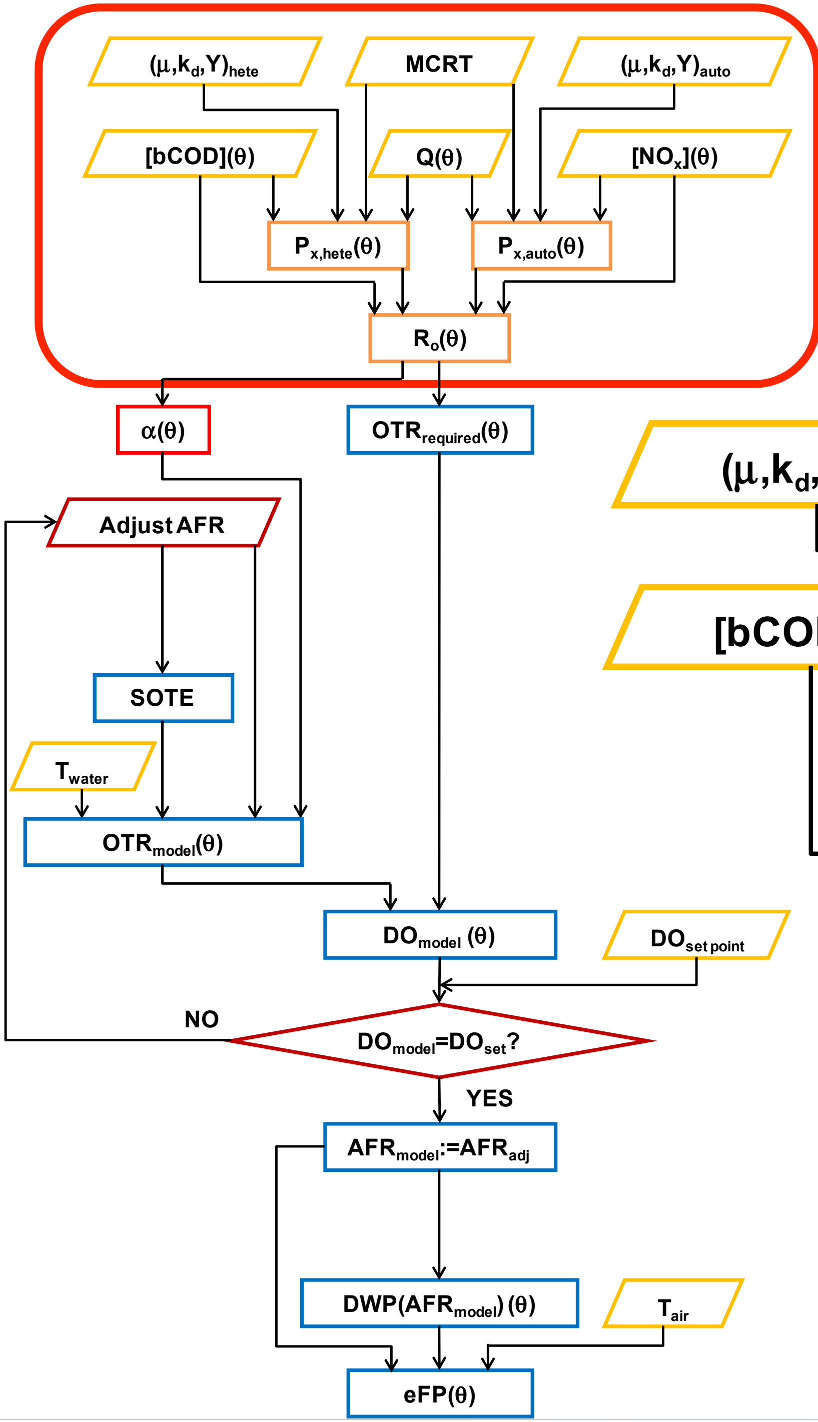
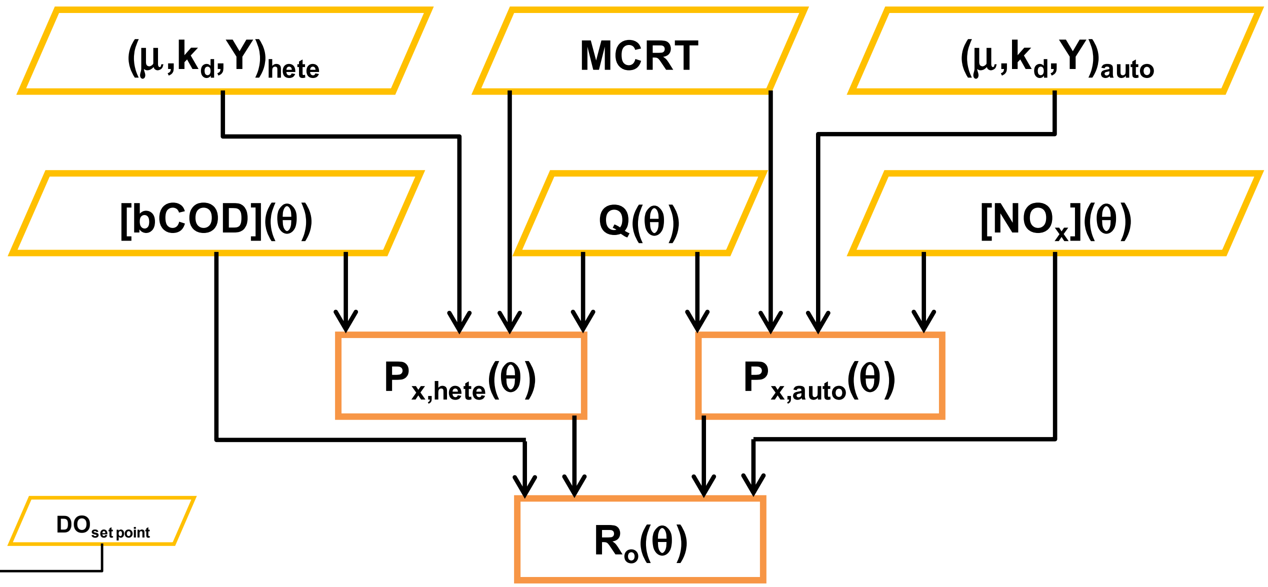
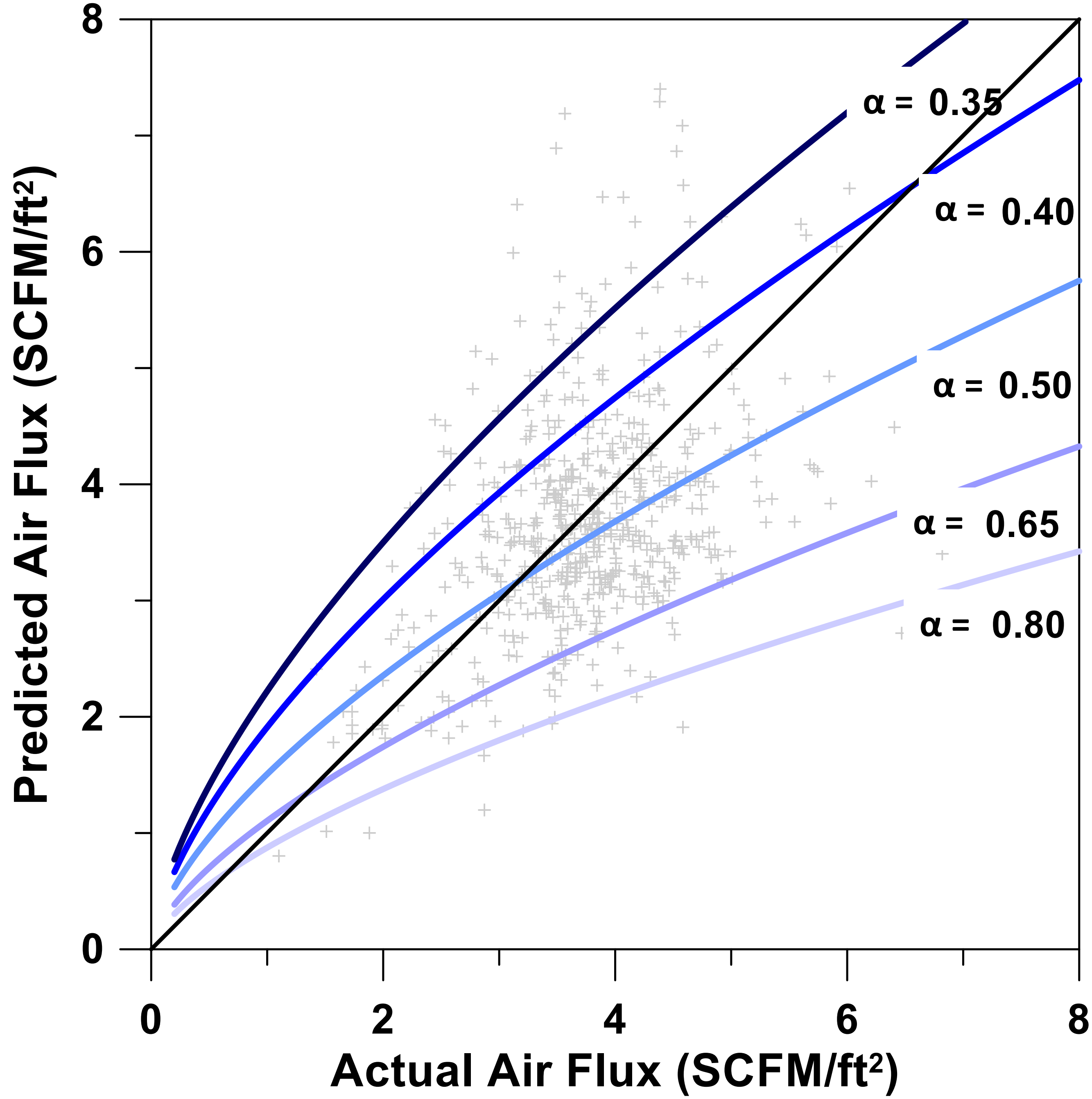
$$\Psi = \frac{DWP_{used}}{DWP_{new}} = \frac{DWP(t)}{DWP(0)}$$



α, EFP: Dynamic Model

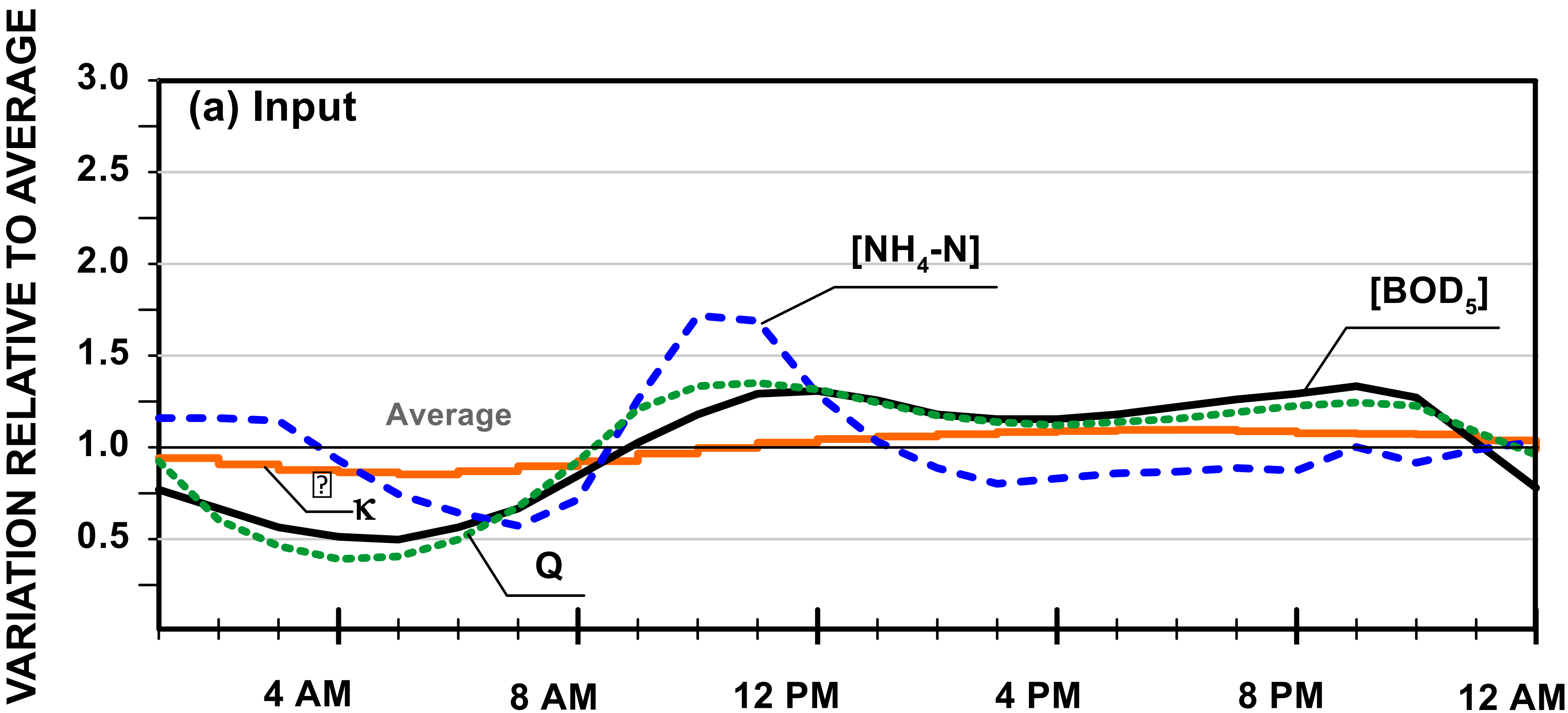




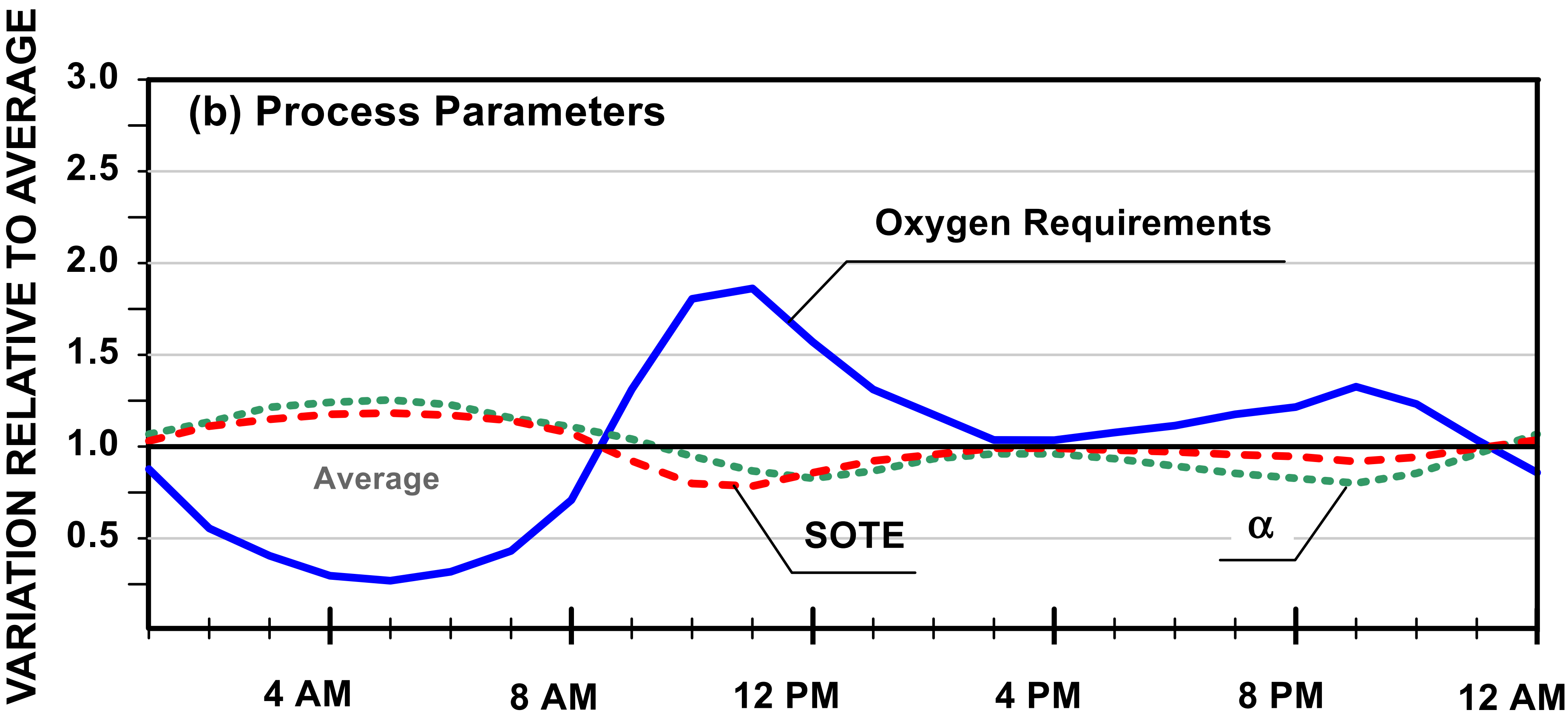


α = 0.35
α = 0.40
α = 0.50
α = 0.65
α = 0.80
Predicted Air Flux (SCFM/ft²)
Actual Air Flux (SCFM/ft²)
0
2
4
6
8

Activated Sludge Process: Diurnal Dynamics



Activated Sludge Process: Diurnal Dynamics



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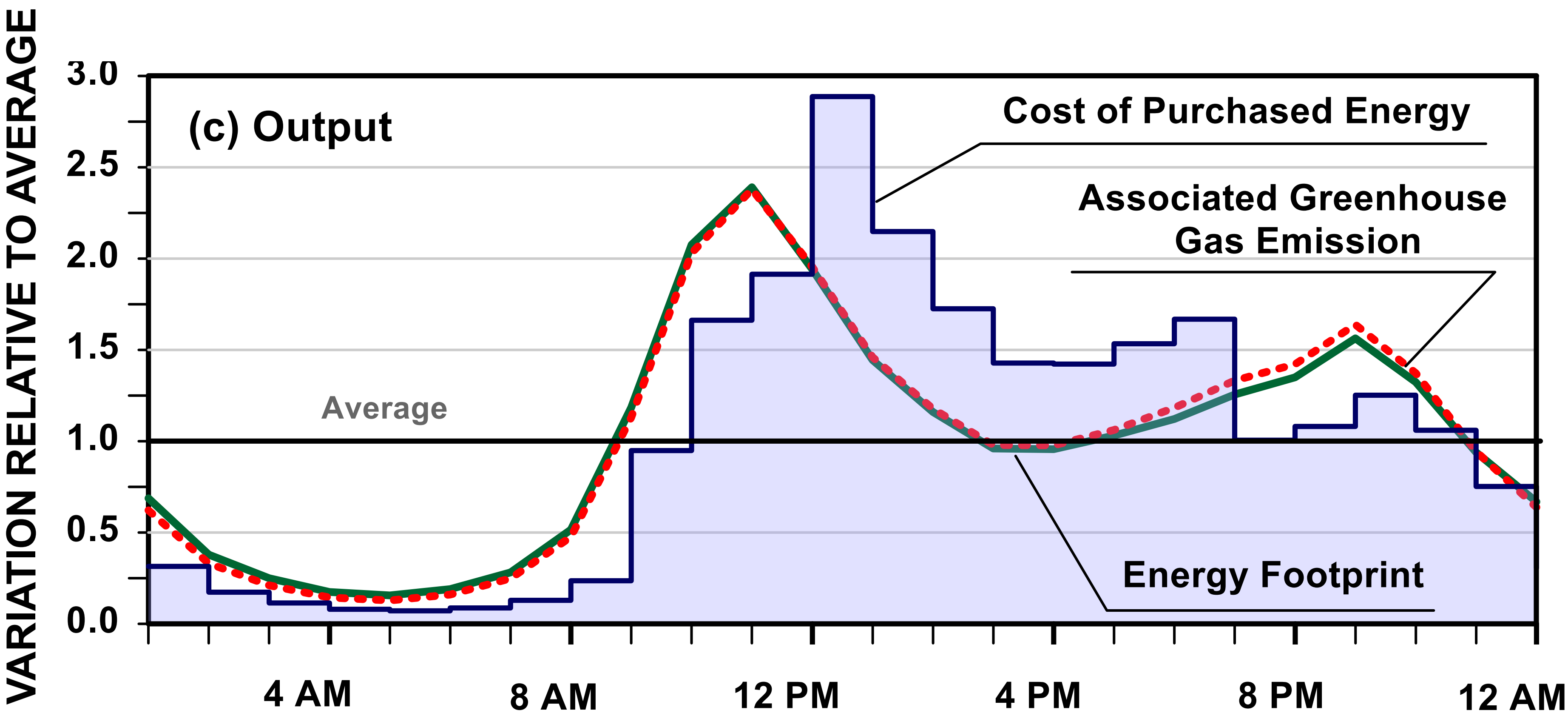

FLOW EQUALIZATION (WHEN APPLICABLE) CAN DO WONDERS

SIDESTREAM LOAD (IF NOT TREATED) SHOULD NOT BE RETURNED AT PEAKS

CONCLUSIONS

In sum

- Step 1: Energy Benchmarking
- Step 2: Energy Footprint Modeling
- Aeration, fouling, and your power bill
- Caveat: uncertain inputs may be key to accurate and realistic modeling (e.g., aeration efficiency)

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DIEGO ROSSO

bidui@uci.edu

www.epl.eng.uci.edu

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