Constructed wetlands for water pollution control

Advance in Technology and Scientific Research

Jun Zhai

September, 2018

Brief Introduction

Advances in CW Technology

New Application Area

Future Perspective

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History of CWs

1900 - 1970

Wetland-based treatment engineering design

In 1965, research on HF CWs began.

1968, FWS CWs in Hungarian

1970 - 1990

North America, Germany began to apply HF CWs to treat domestic sewage.

HF CWs are developing faster and faster.

In North America, FWS CWs is rapidly spread and developed, and is widely used in tertiary treatment of various sewage wastewaters.

In Brazil, VF CWs appeared and VF-HF wetlands were builted in France.

1990 - 2000

Many types of CW have been widely used.

type of wastewater	type of CW	location
refinery	HF	South Africa
	FWS	China
pulp and paper	FWS	USA
	HF	USA
pesticides/herbicides	FWS	USA
	VF	UK
fish pond effluent	FWS	USA
	HF	USA
abattoir facility	HF	Ecuador
	FWS, HF	Norway
landfill leachate	HF	USA
	HF	Slovenia
explosives	FWS	USA
	HF	USA
mining waters	FWS	Canada
	HF	USA
	VF	Netherlands
dairy	VF-HF	France
	HF	New Zealand
cheese dairy	VF	Germany
chemical industry	HF	UK
textile industry	HF	Australia
	HF	Slovenia
food processing	HF	Italy
pig farms	HF	China
highway runoff	HF	UK
airport runoff	HF	Switzerland
greenhouse runoff	HF	Canada
urban runoff	FWS	Australia
hydrocarbons	HF	USA

2000 - present

New developments in CW

·Composite CW, higher processing effect

·Treatment of sewage containing special pollutants

·Research on matrix phosphorus removal

·Artificial wetland hydraulics and pollutant control model

·Artificially enhanced in CW

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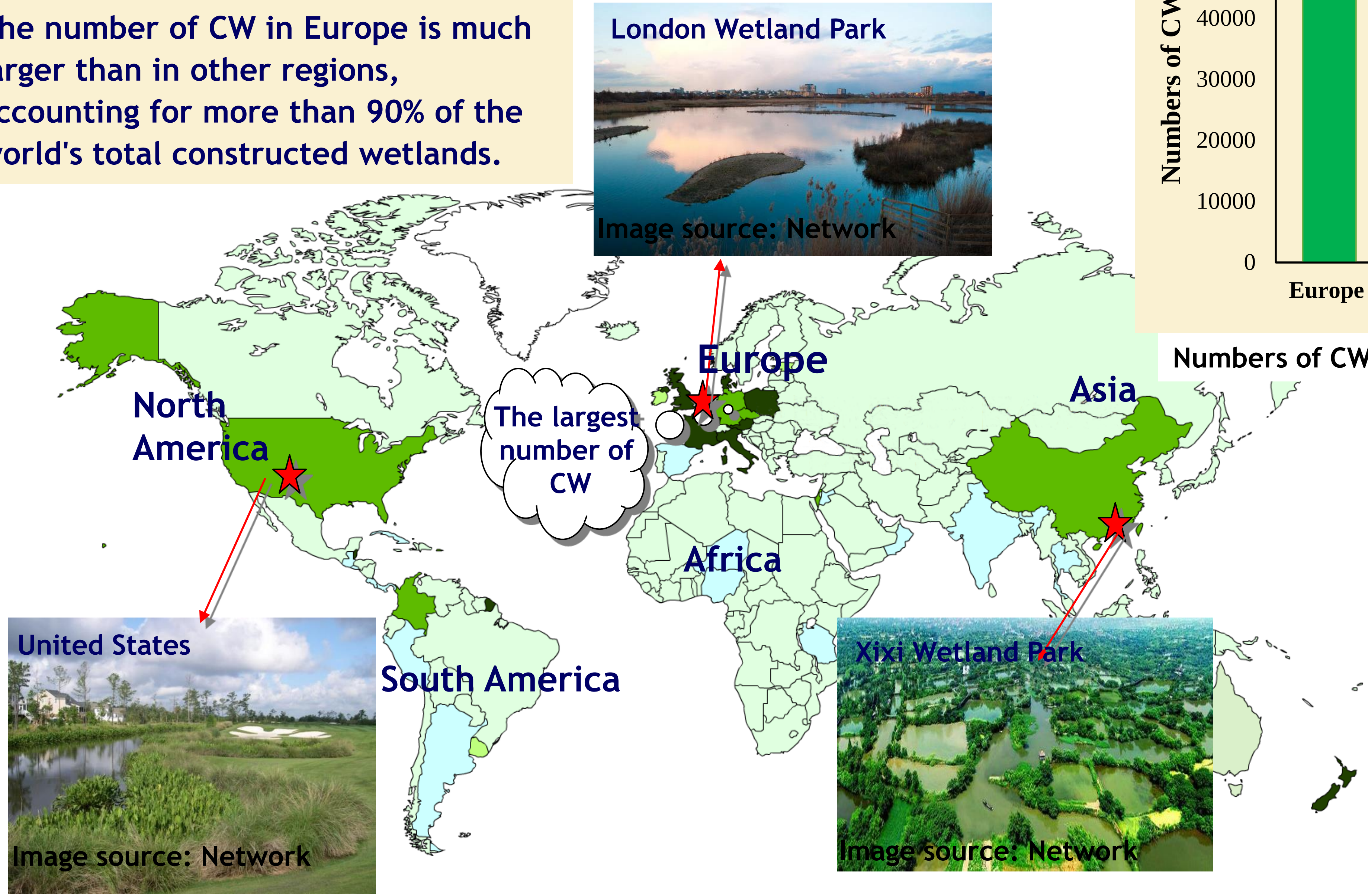
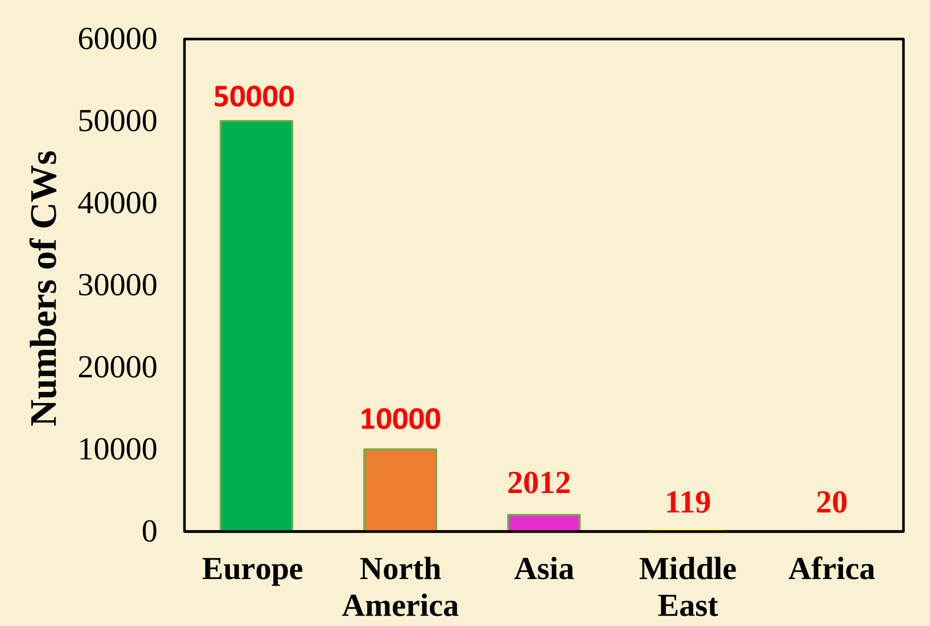
The distribution of CW

The number of CW in Europe is much larger than in other regions, accounting for more than 90% of the world's total constructed wetlands.



The quantities distribution of CW during 2012 to 2014



Numbers of CW over world (Yan and Xu, 2014)

CW in China

- The systemic studies started from 1980s, and the first CW was built in 1990, Changping, Beijing.
- In July 1990, a demonstration engineering of CW, scaled 3100m^3/d was constructed in Bainingkeng, Shenzhen. It combined with subsurface flow CW and stabilization pond.
- In 1994, IWA CW conference was hold in Guangzhou.
- In 2014, IWA CW conference Return back China in Shanghai
- At present, it extends to be utilized in municipal wastewater treatment, industry wastewater treatment, eutrophication water quality improvement, leachate treatment, storm water treatment and non-point source pollution control.

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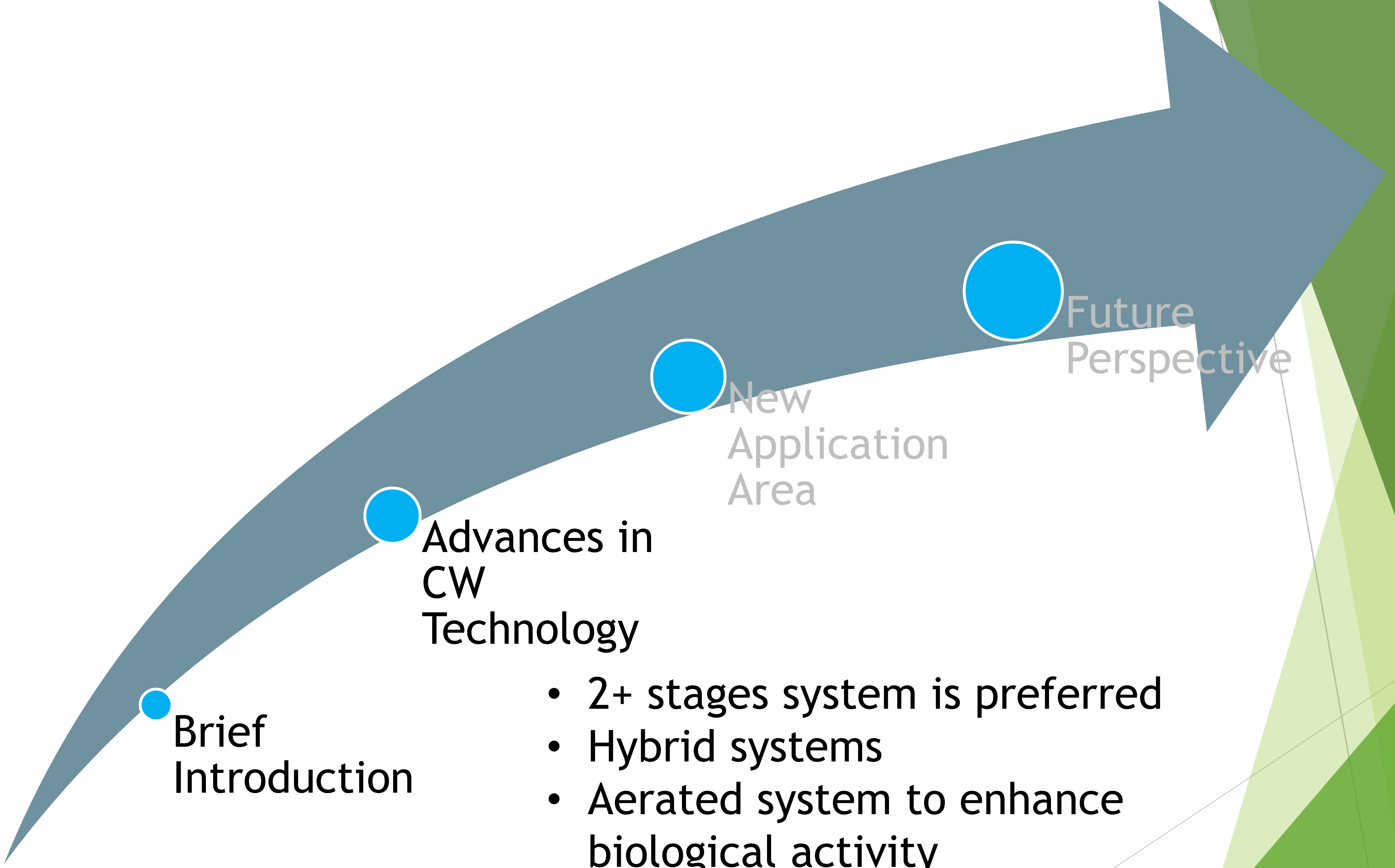
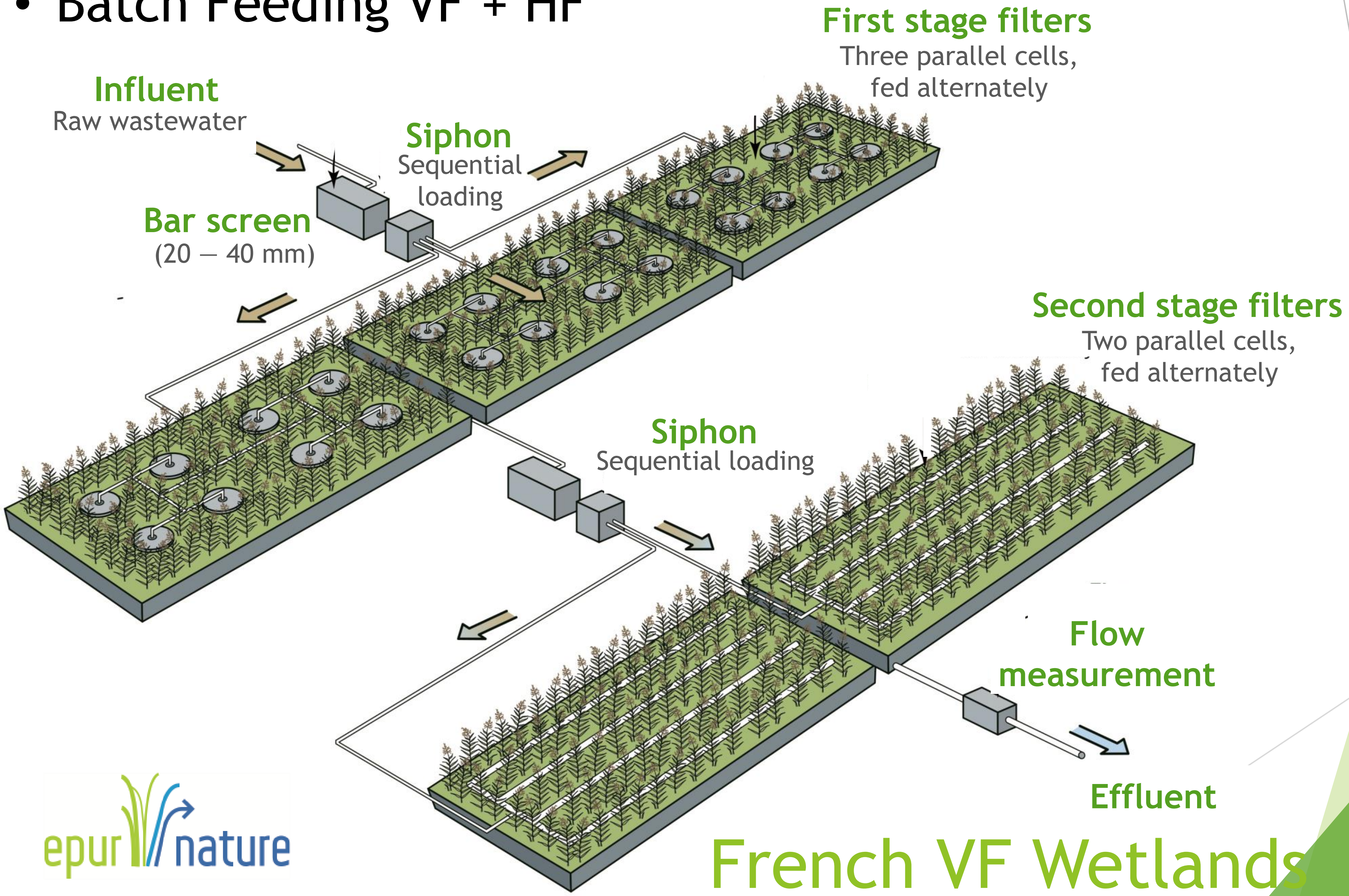


- 2+ stages system is preferred
- Hybrid systems
- Aerated system to enhance biological activity
- P removal

- Batch feeding VFs
- Batch Feeding VF + HF



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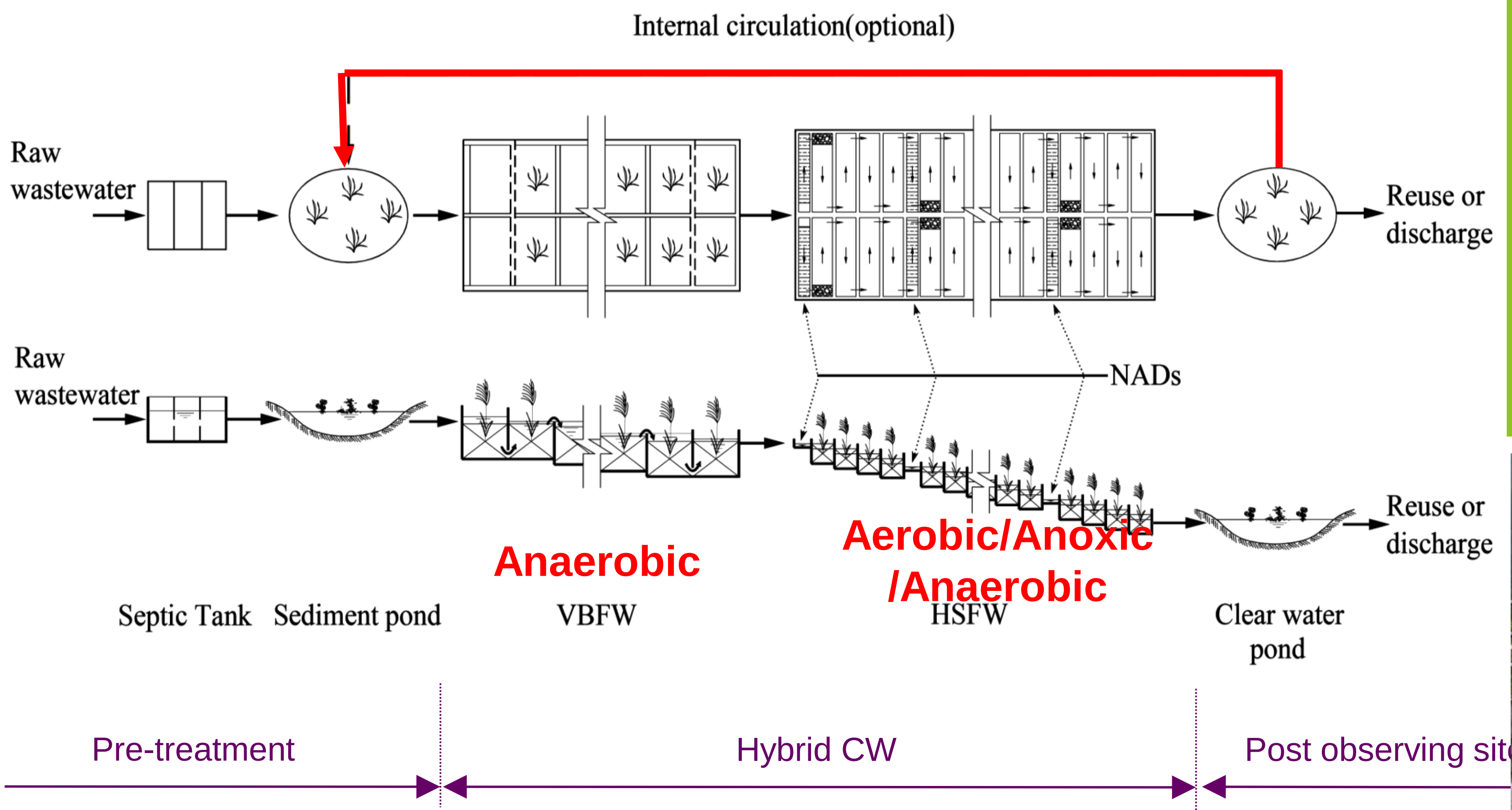
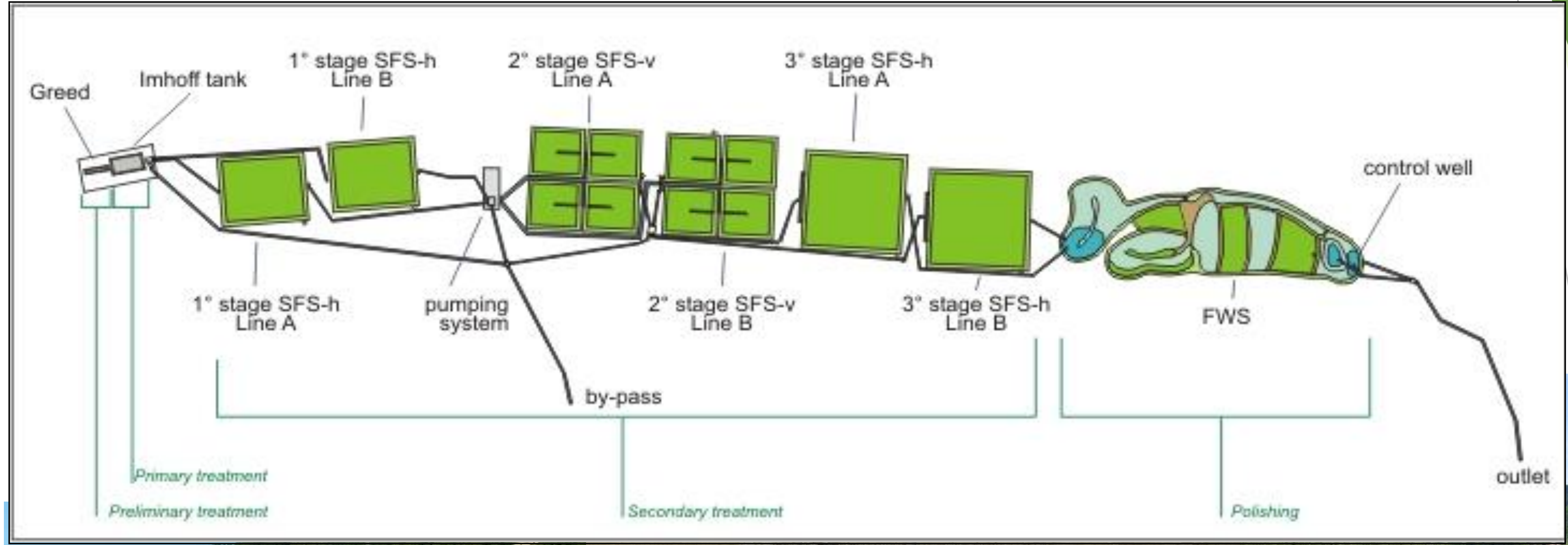
French VF Wetlands

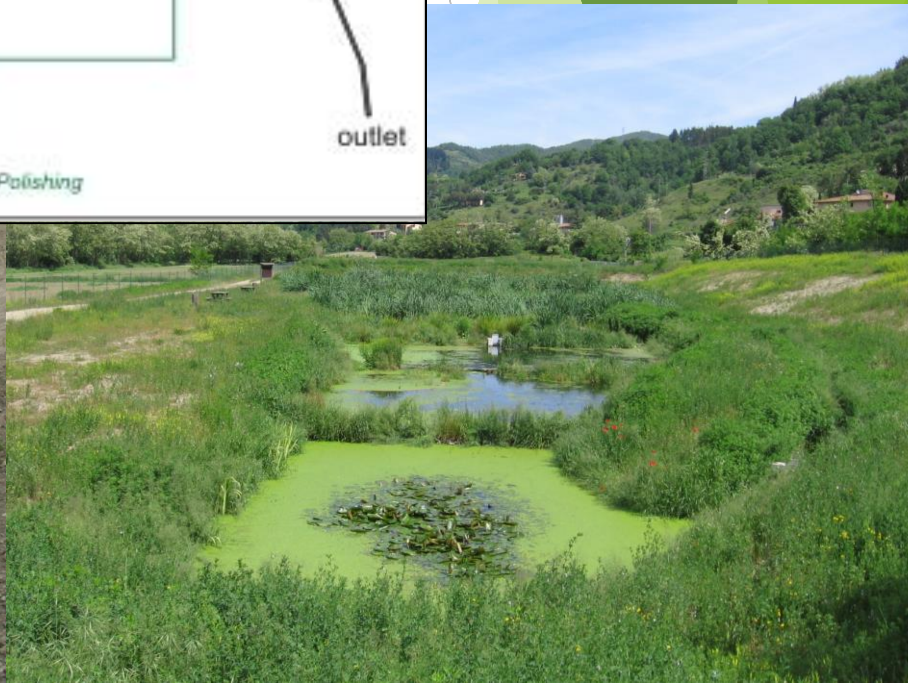
Hybrid systems: different stages for different reactions



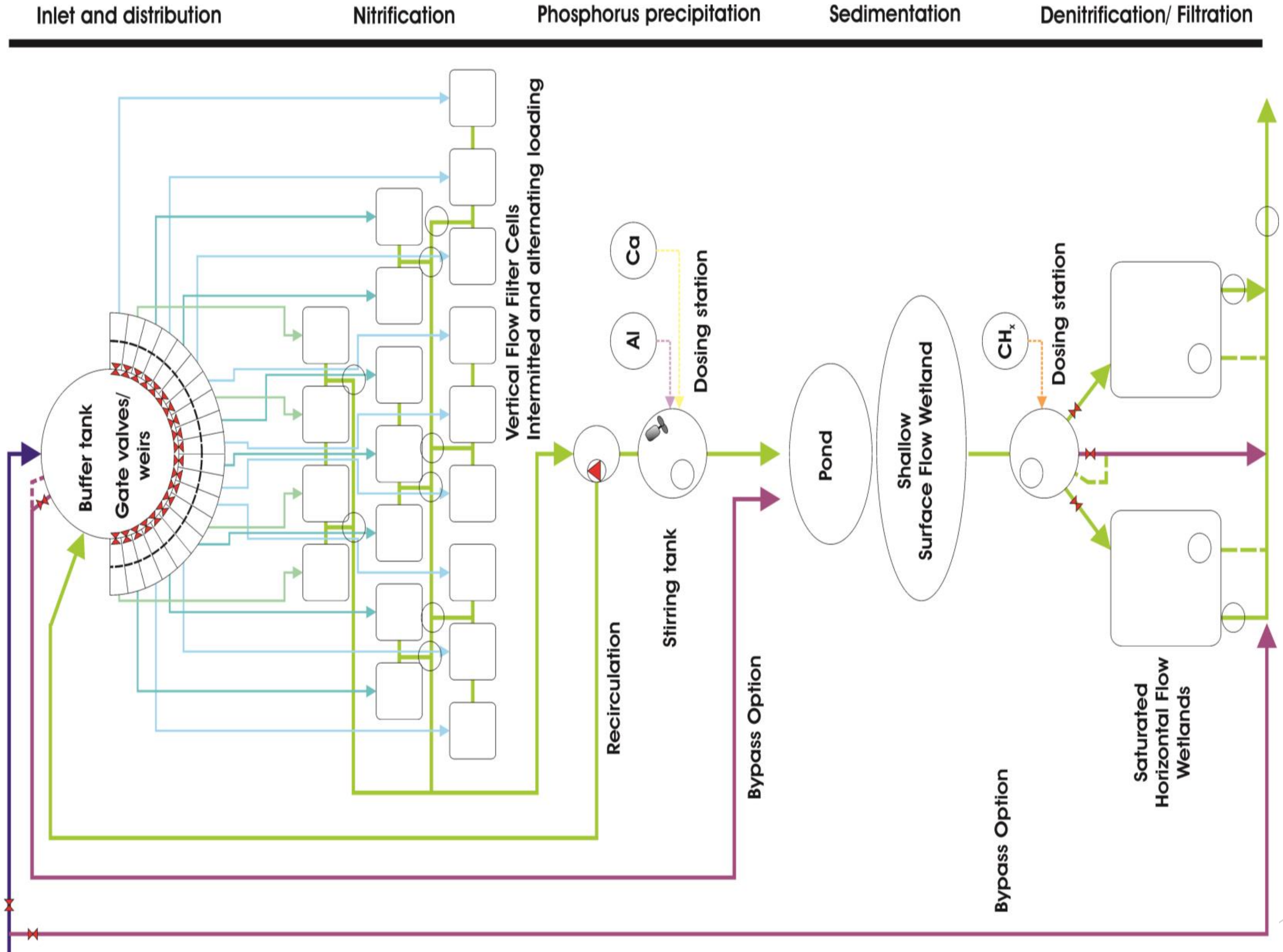
Hybrid systems: different stages for different reactions

From: Fabio Masi

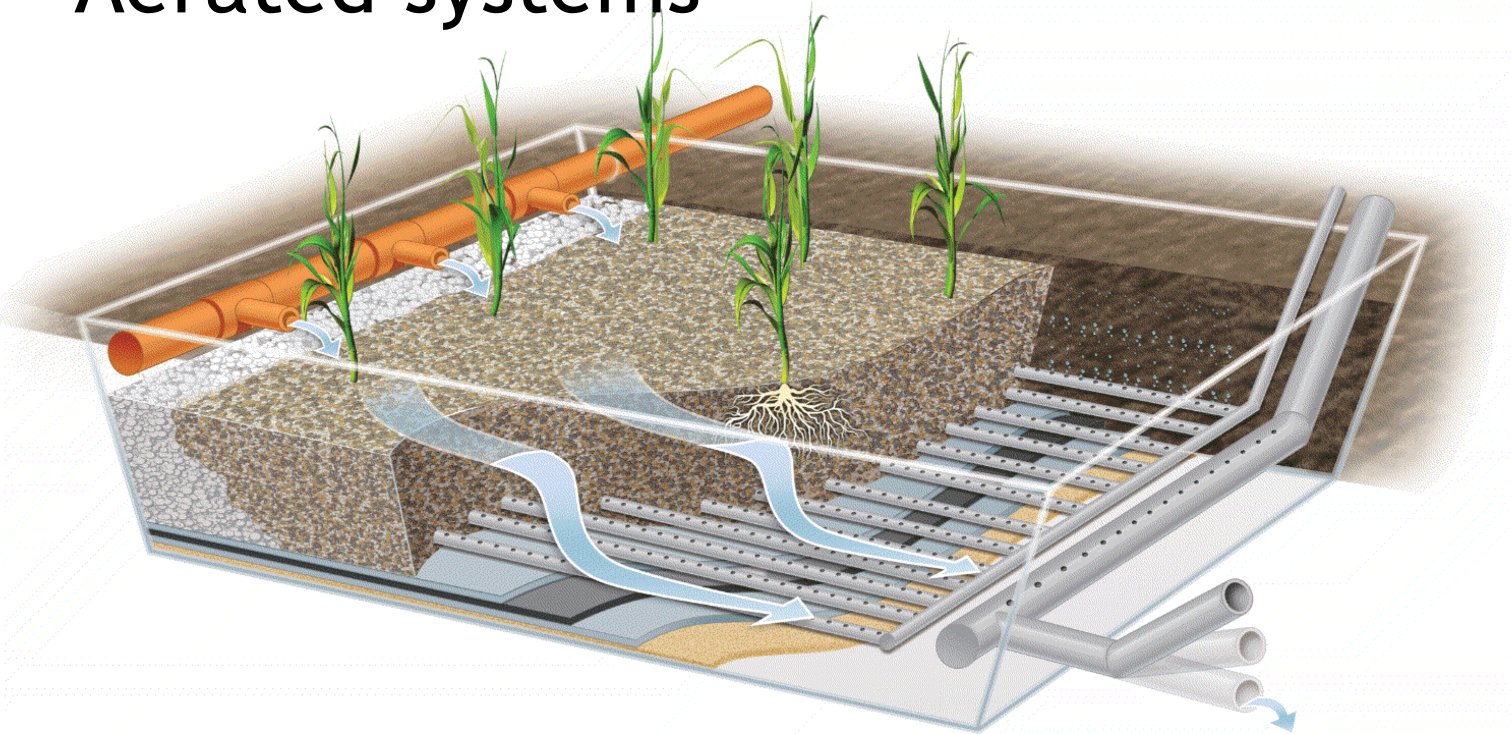




Hybrid systems: different stages for different reactions



Aerated systems

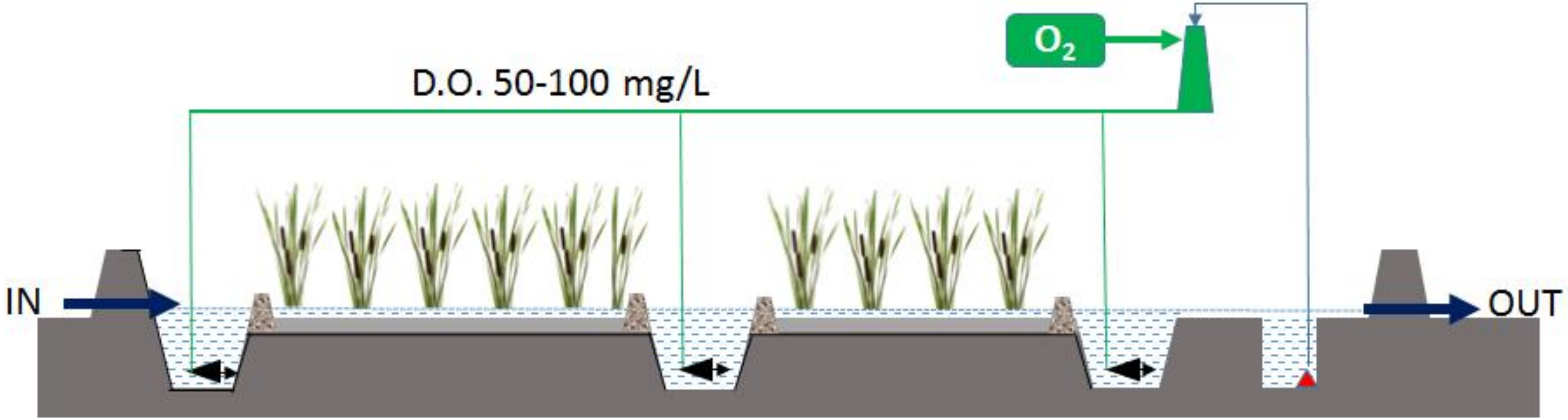


from: Scott Wallace

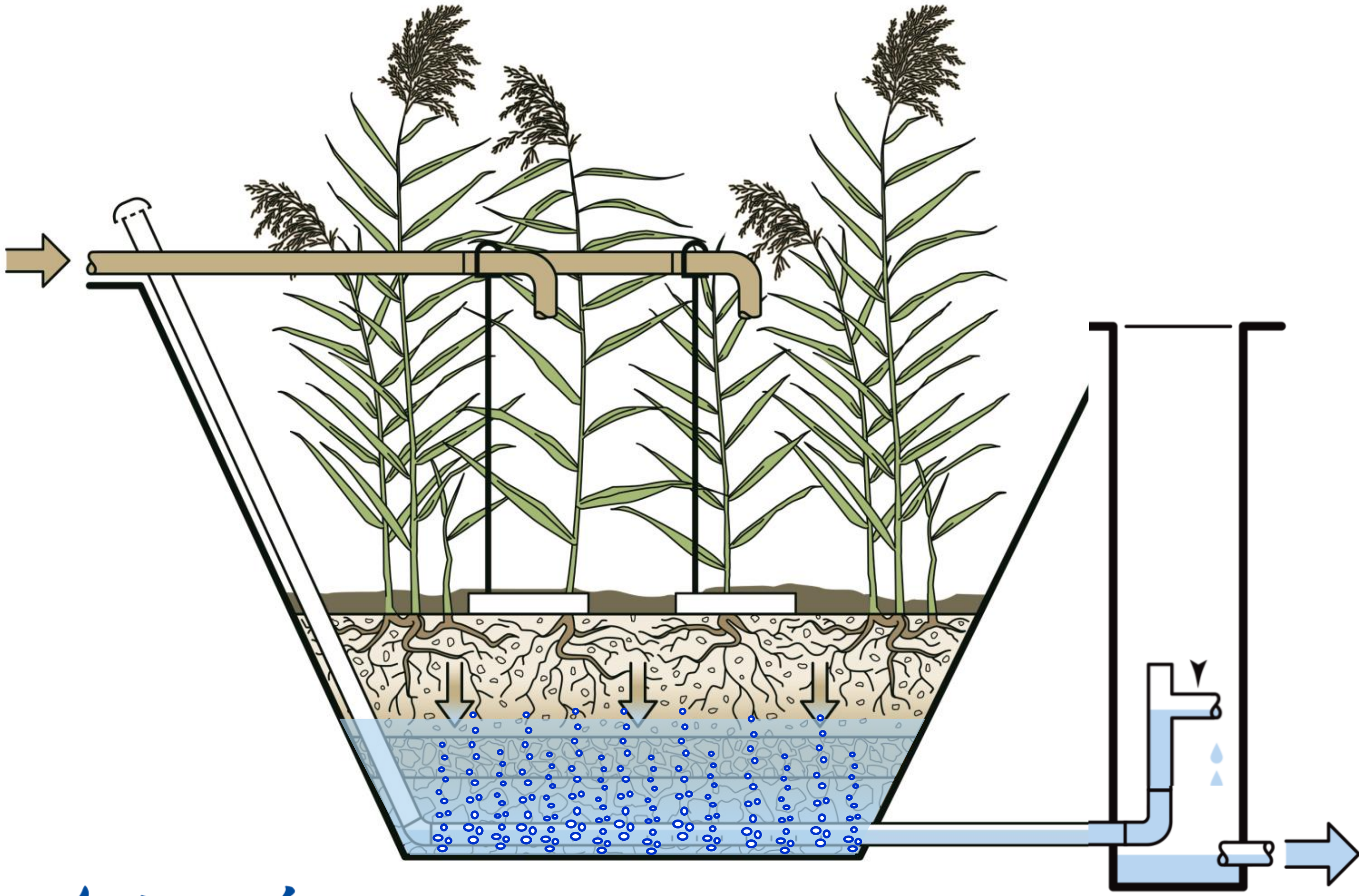
Aerated systems

New CW: Sidestream oxygenation CW

- Aerated pure oxygen to achieve nitrification
- Bench-scale pilot to full scale construction (1.5 MLD)
- Reduced the area required for nitrification by over 90%



New CW: French VF + areation



- Patented Concept
- Domestic wastewater, high-strength wastewater (agro-food industry, winery) with variable loads
- Populations up to 5,000 PE
- Potential for effieicnt TN removal (< 15 mg/L)
- Relatively low energy requirements

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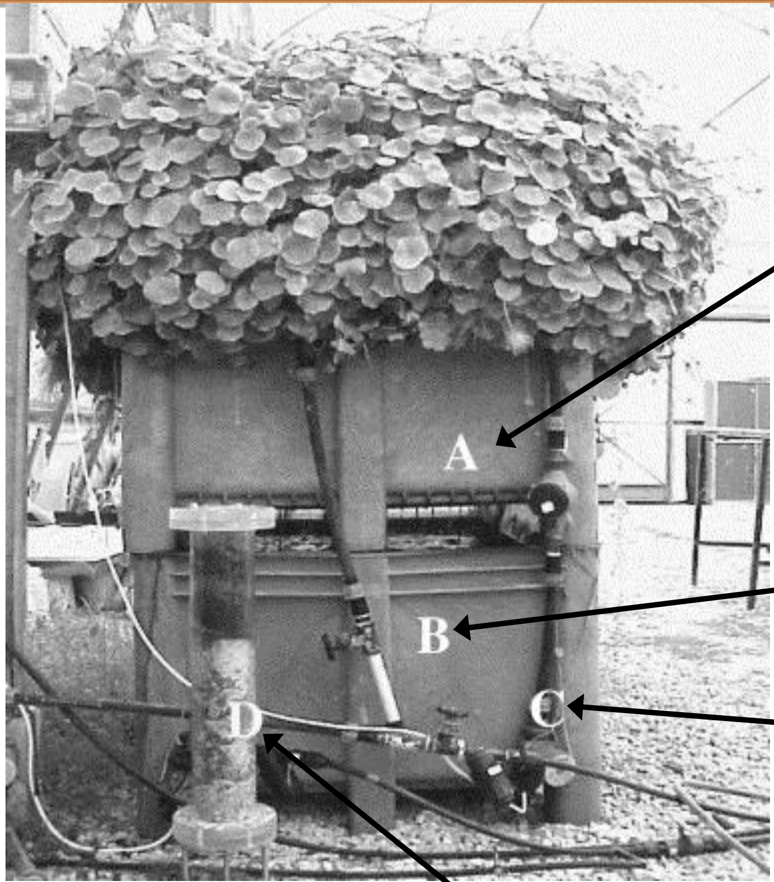
New CW：RVFCW

Recycling vertical flow constructed wetland (RVFCW)

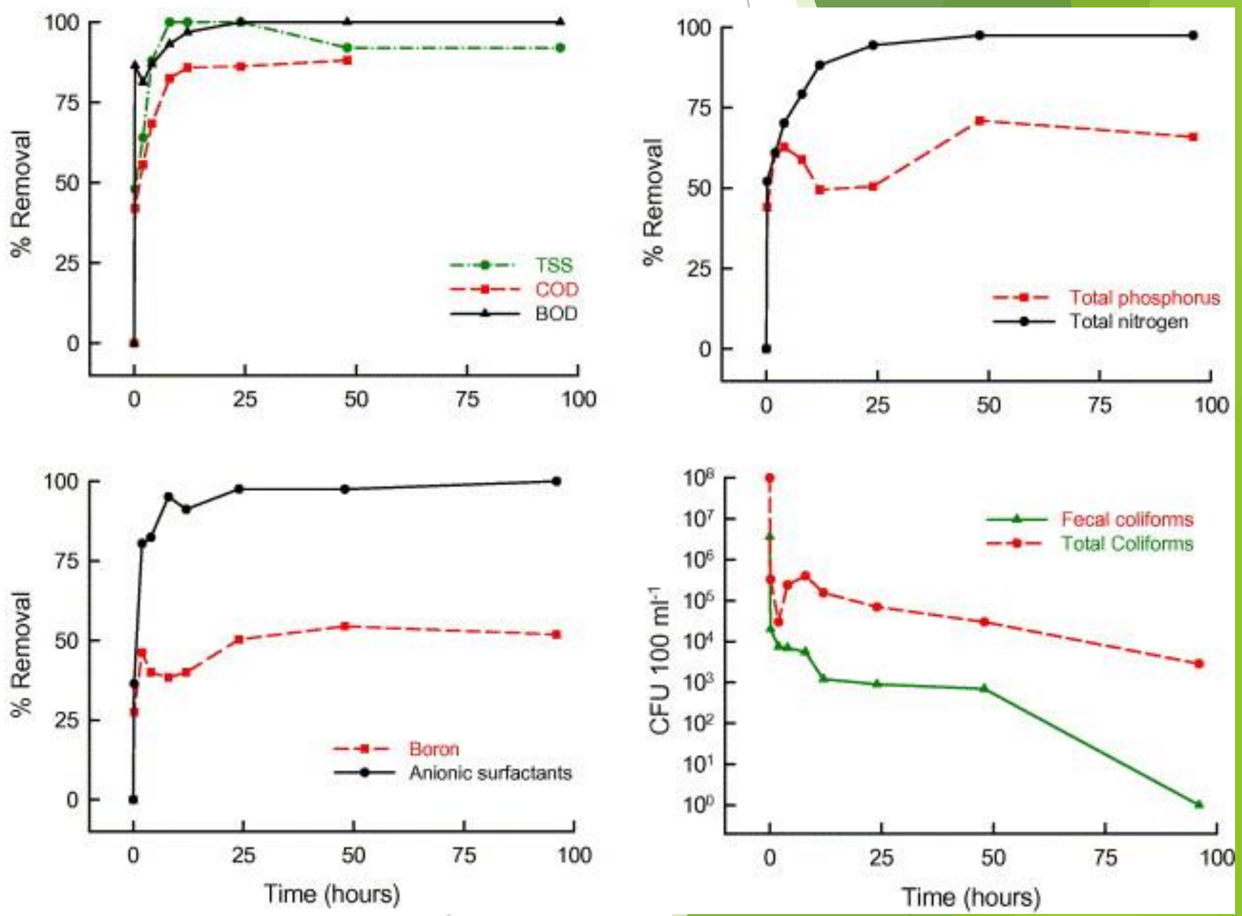


vertical flow constructed wetland

reservoir

recycling pump

demonstration of filter media layers



Gross et al., 2007

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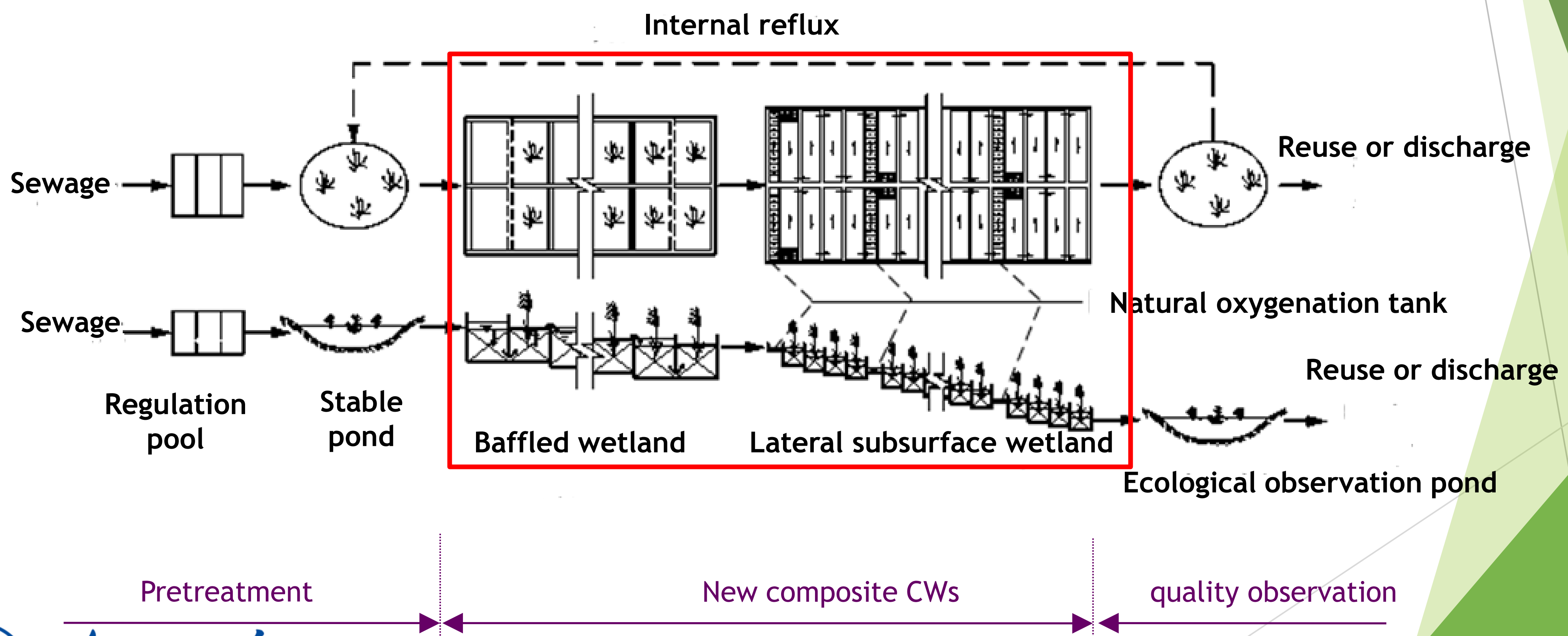
New CW：Hybrid CW systems

vertical baffling + lateral subsurface wetland



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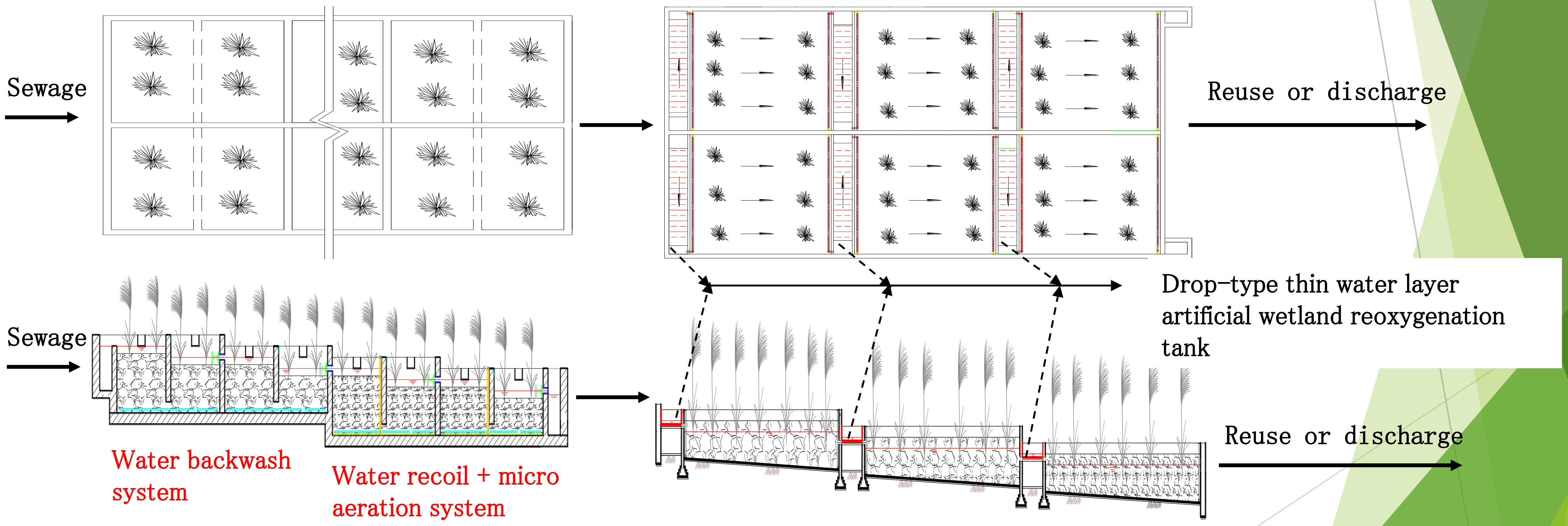
New CW：Hybrid CW systems

Micro-aeration, self-cleaning, high-load hybrid CW



Vertical baffle wetland

Lateral subsurface wetland

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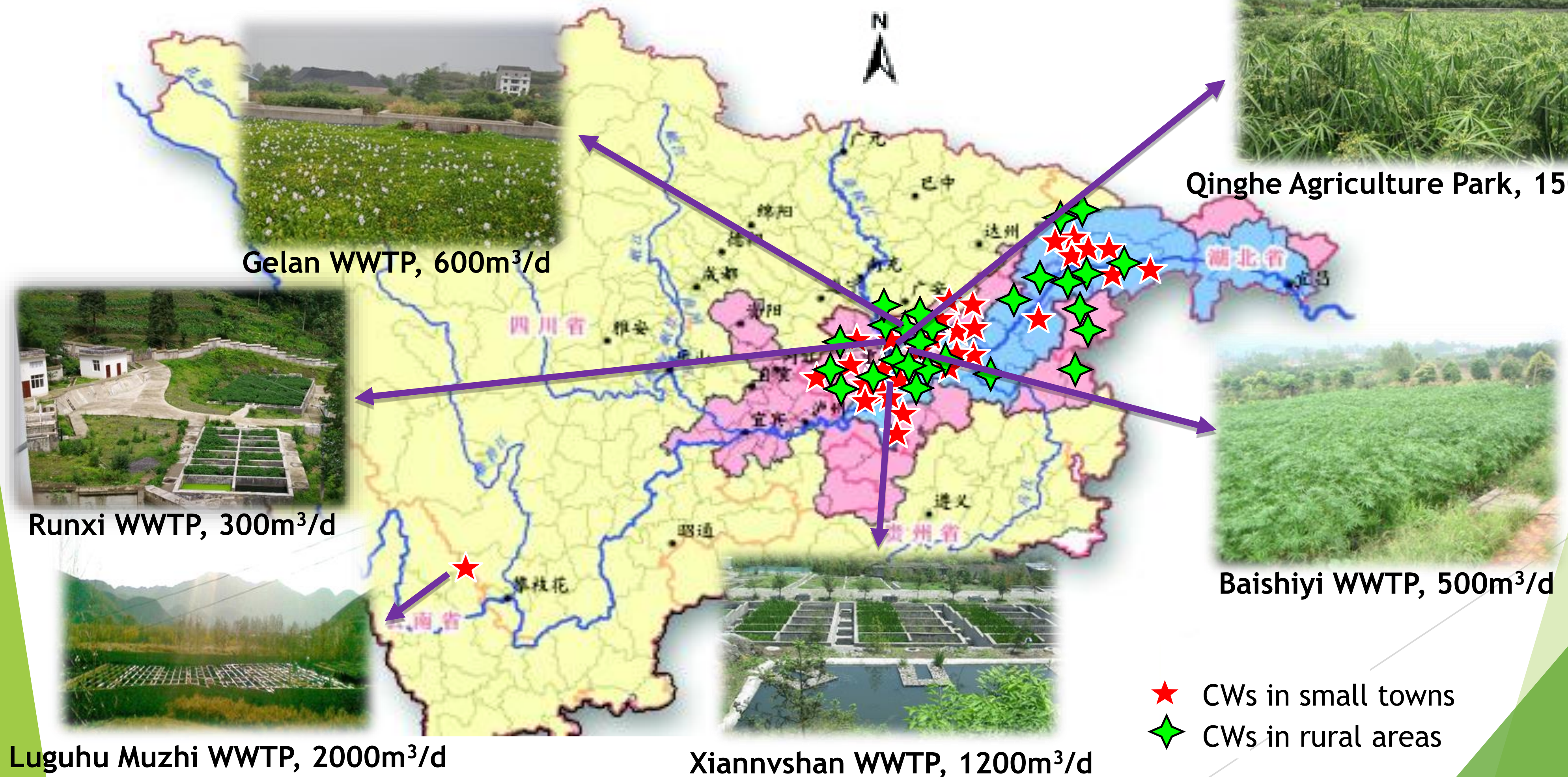
New CW：Hybrid CW systems

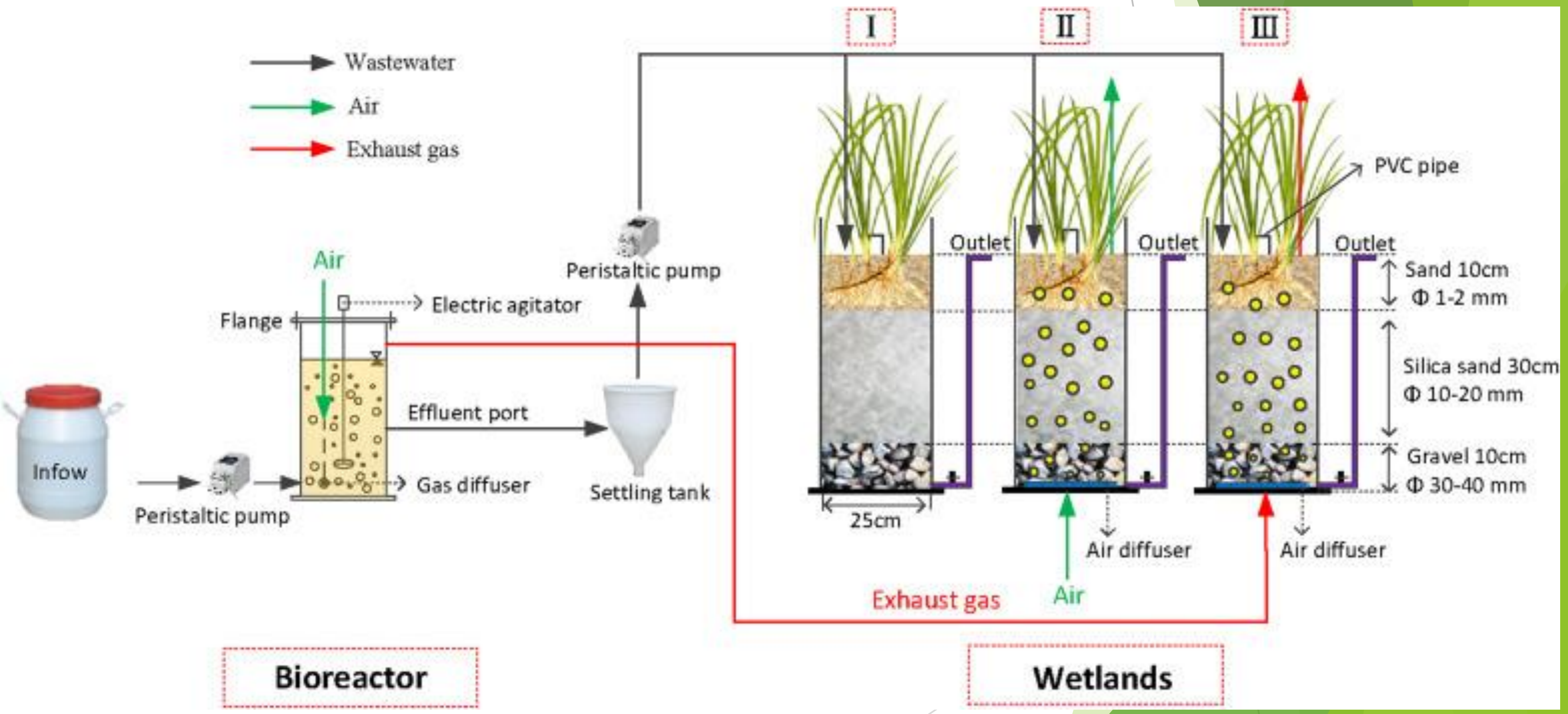
Municipal wastewater treatment in Southwest China



New CW：Hybrid CW systems

aerated vertical flow constructed wetland

- TN and NH_4 removal improved
- Odorous gases, N2O and aerosol in waste gas were significantly reduced



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Zhang et al., 2018

Phosphorus removal in CW systems

- Removal mechanisms
  - Substrate adsorption
  - Plant uptake
  - Precipitation
- Substrate rich in Al^{3+} , Fe^{3+}, and Ca^{2+} is good for P removal

Phosphorus removal in CW systems

- Some large-scale SF wetlands can achieve sustainable phosphorus removal
- Low-dose alum addition for PO_4-P removal (no coagulation)
- Geochemical augmentation increases PO_4-P removal rates in wetlands by a factor of 20
- Influent TP = 0.6 mg/L
  Effluent TP < 0.1 mg/L
- **David Austin**

Huie Constructed Wetlands, Clayton County, GA

Source: American Academy of Environmental Engineers & Scientists.

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New Application Area

Industrial wastewater treatment

Landill leachate treatment (Leiria, Portugal)

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New Application Area

Waterworks sludge

New Application Area

- eutrophication water quality improvement by CW

New Application Area

Urban stormwater runoff treatment (Charleston, USA)

Drink water source treatment (Jiaxing, China)

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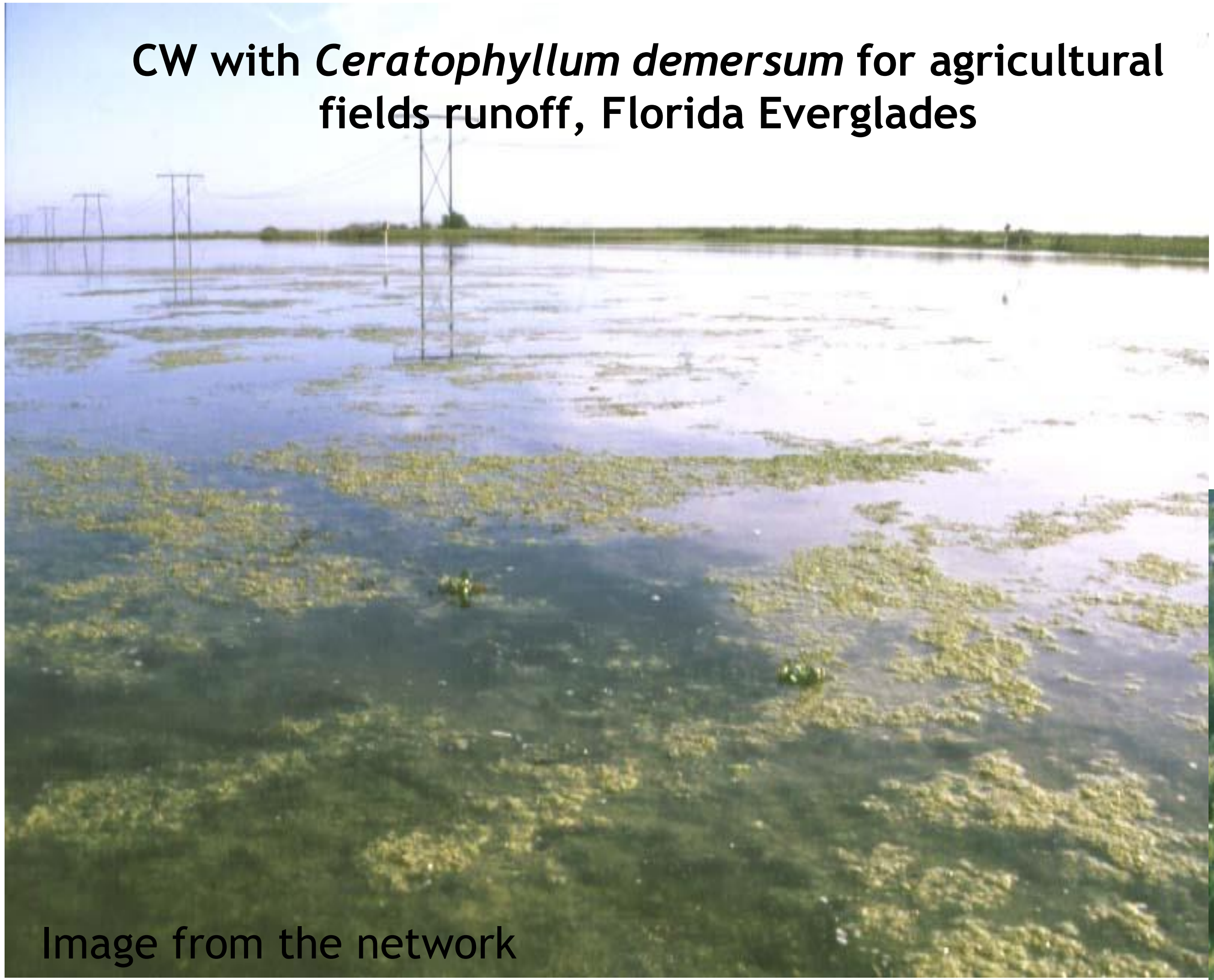
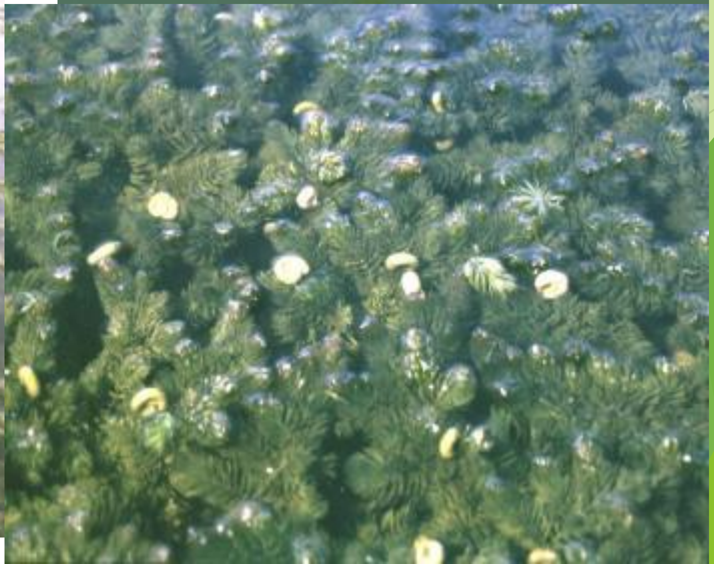
New Application Area

- non-point source pollution control by CW



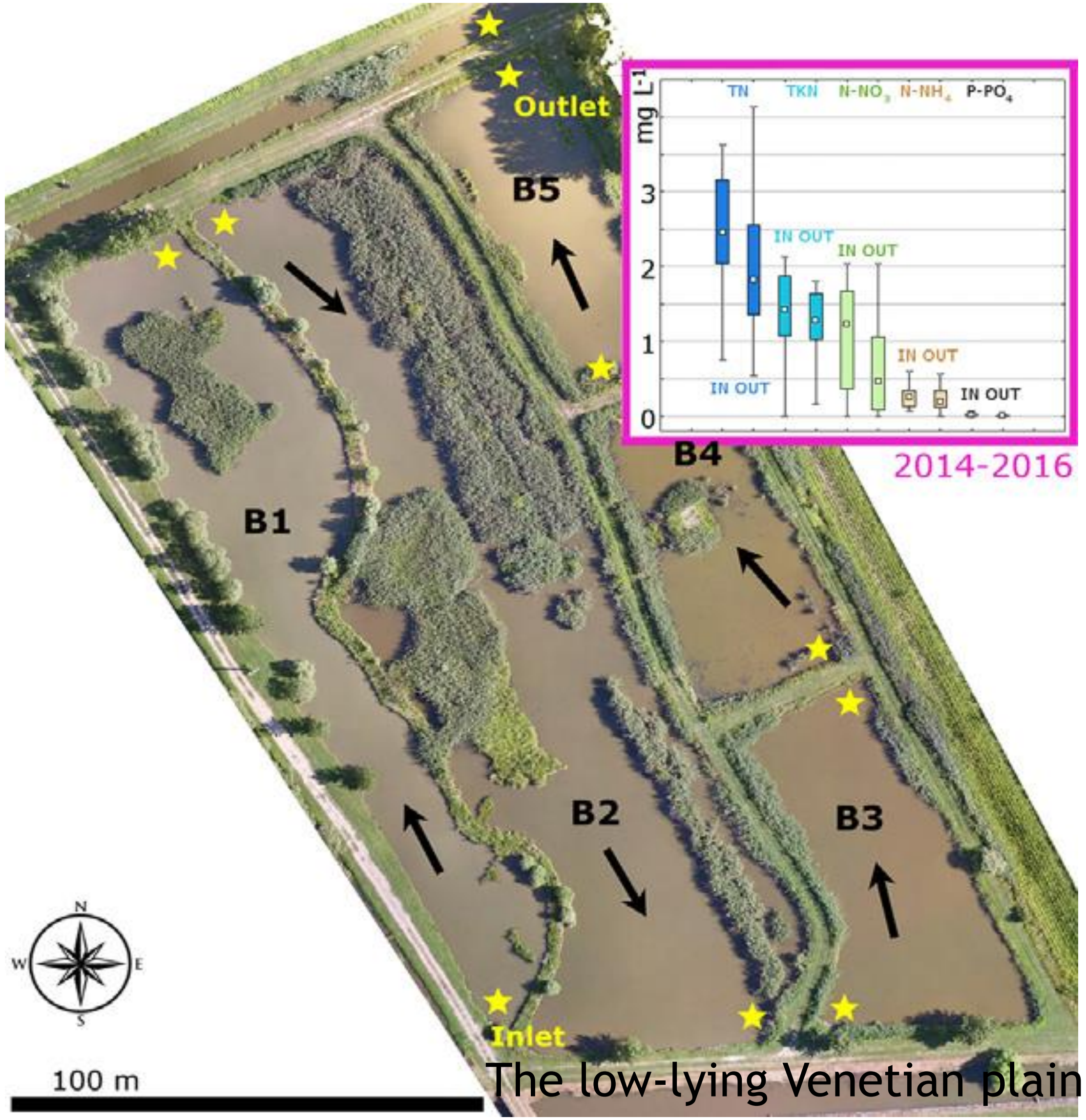
CW with *Ceratophyllum demersum* for agricultural fields runoff, Florida Everglades

Image from the network

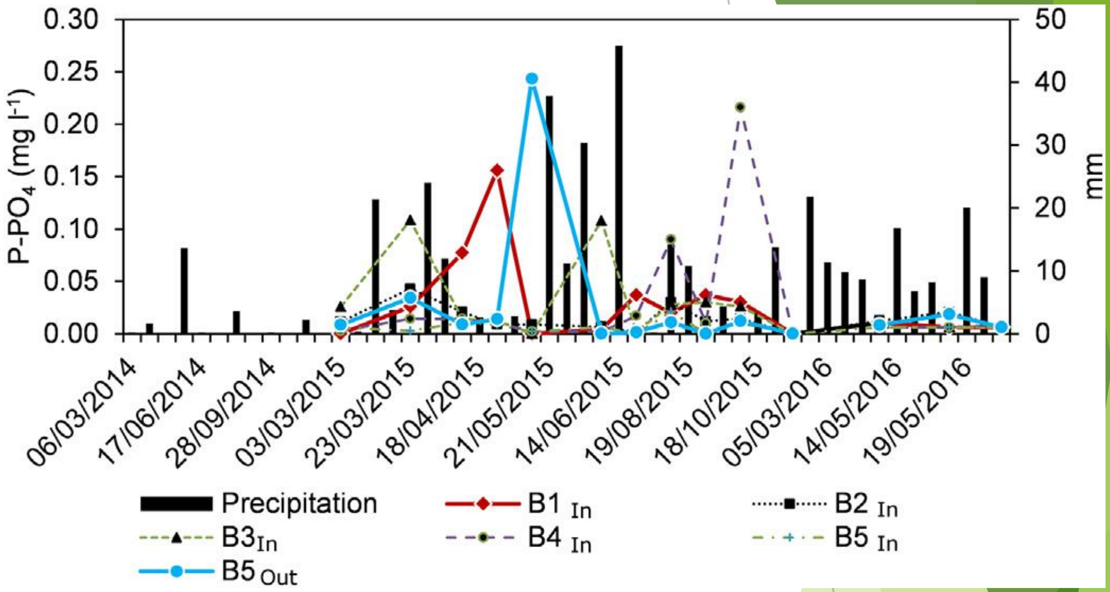


New Application Area

- Agricultural waters treated by FWS CWs



The low-lying Venetian plain

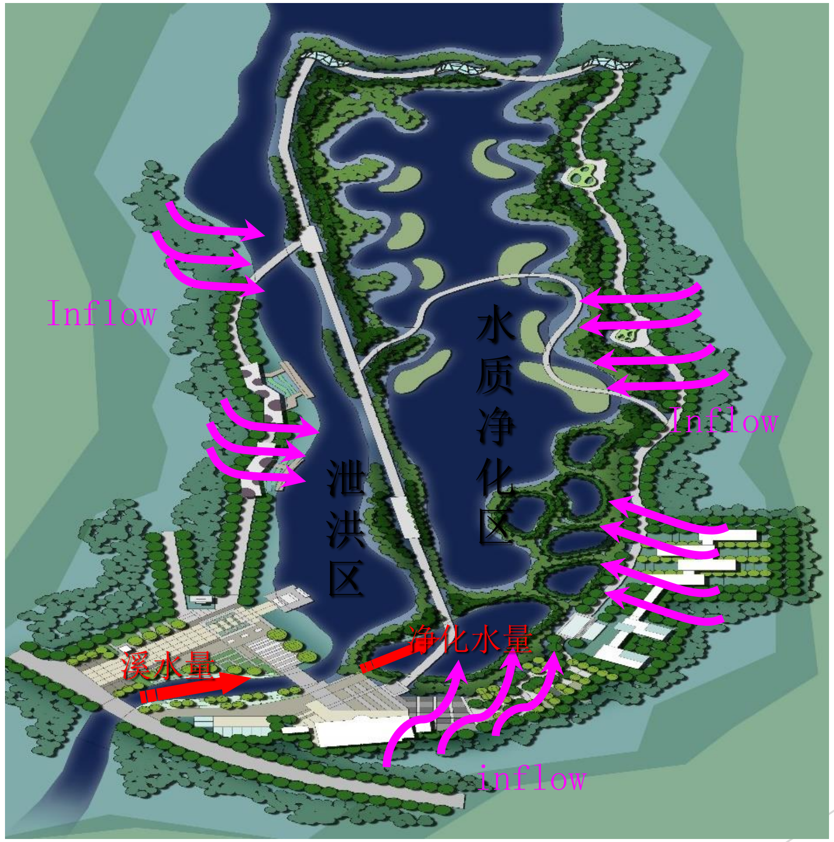


Concentrations of ammonium (N-NH_4) and orthophosphate (P-PO_4) were generally low (<1 and <0.3 mg/l for N-NH_4 and P-PO_4, respectively), with average yearly mass removals of 50 kg for N-NH_4 and 9 kg for P-PO_4.

Ferro et al., 2018

New Application Area

water source quality protection



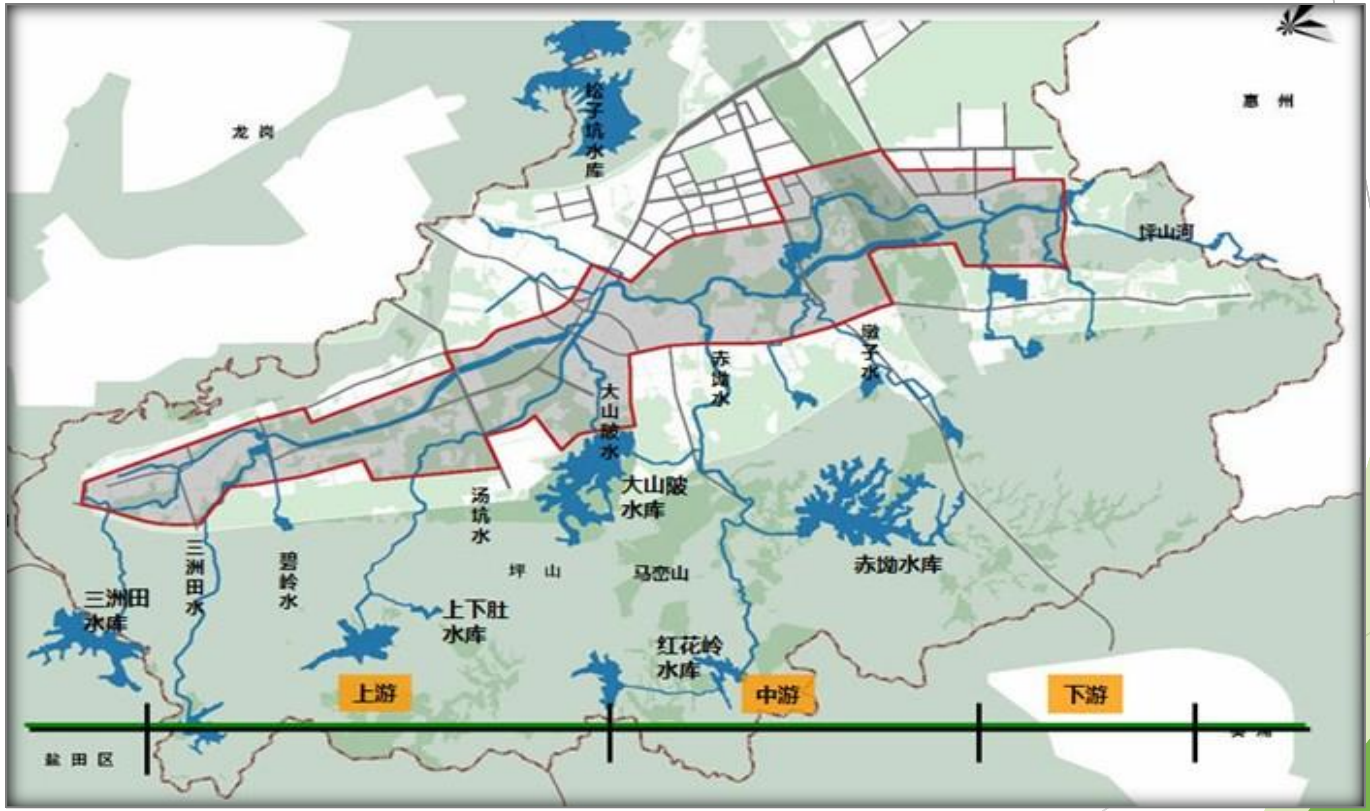
Nanpeng Reservoir water quality protection

▶New Application Area

River water quality protection

Pingshan River Wetland in Shenzheng

136500m^3/d



Upgrade WWTP effluent to surface water source (Class IV)

- Brief Introduction
- Advances in CW Technology
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- Research Perspective

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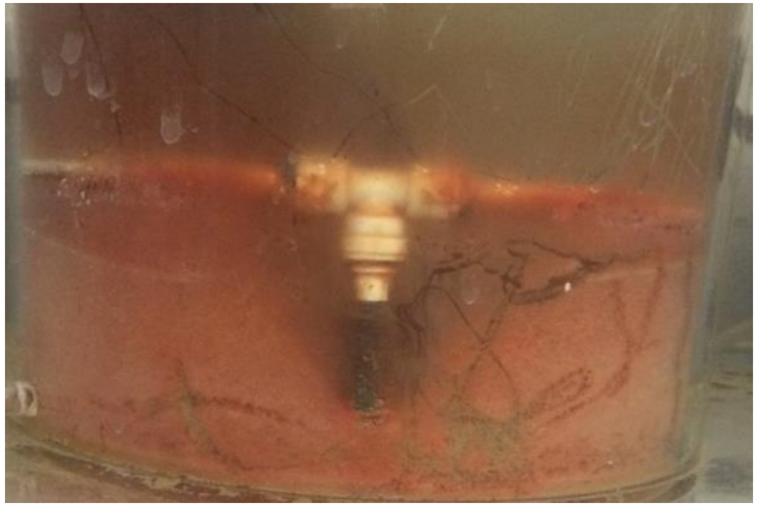
Nitrogen removal in CW systems

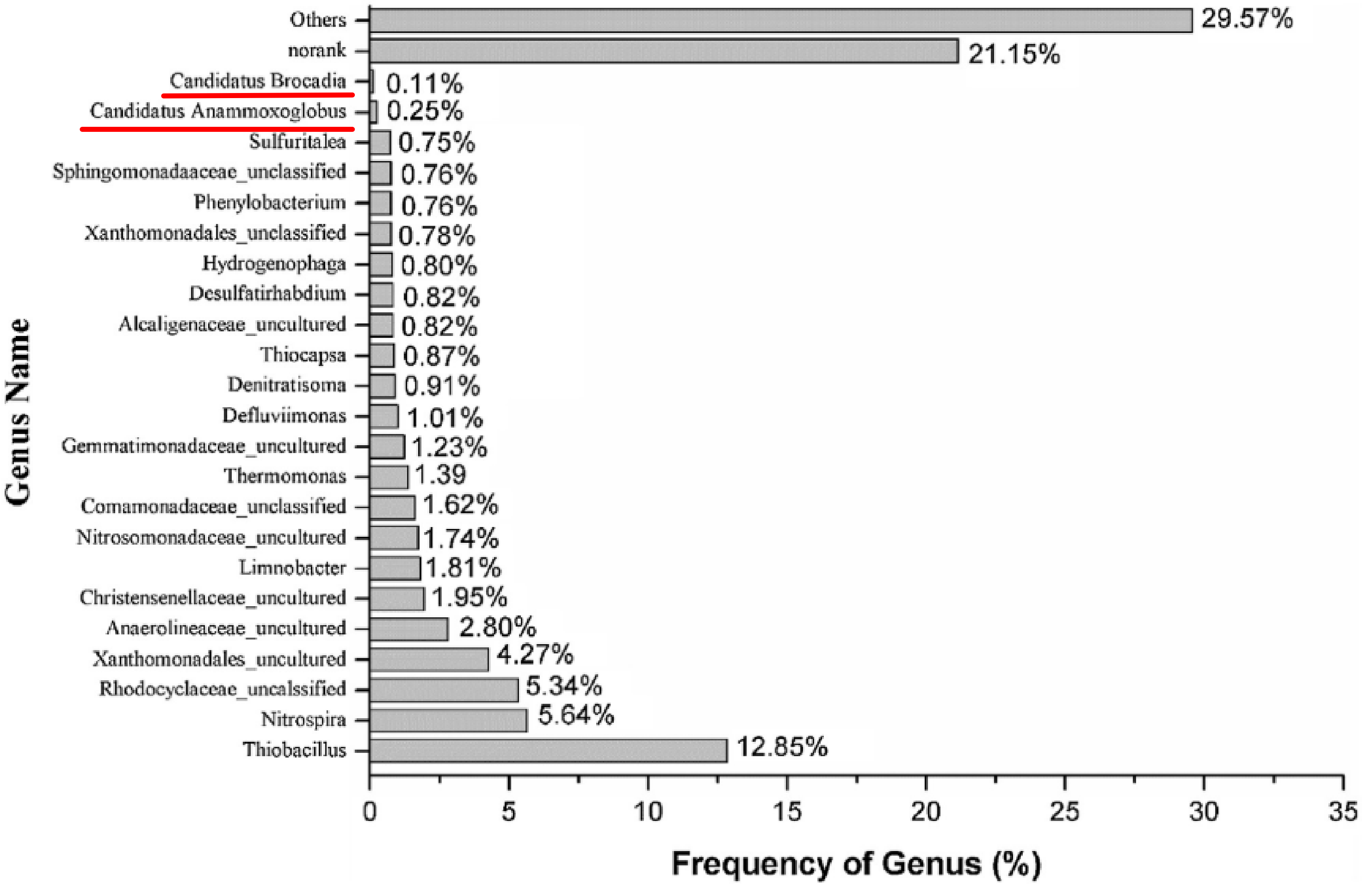
- Nitrogen removal is poor in CWs, constraining their application
- TN removal varies from 10% – 60% (Machado et al., 2017)
- The hybrid CWs are more efficient in N removal (Vymazal 2013).
- Anaerobic ammonia oxidation may be important in N removal

Nitrogen removal in CW systems

The Role of Anammox



Enrichment of anammox bacteria *Candidatus* Jettenia sp. and *Candidatus* Brocadia caroliniensis



Microbial community in a hybrid CW (Zhai et al., 2016)

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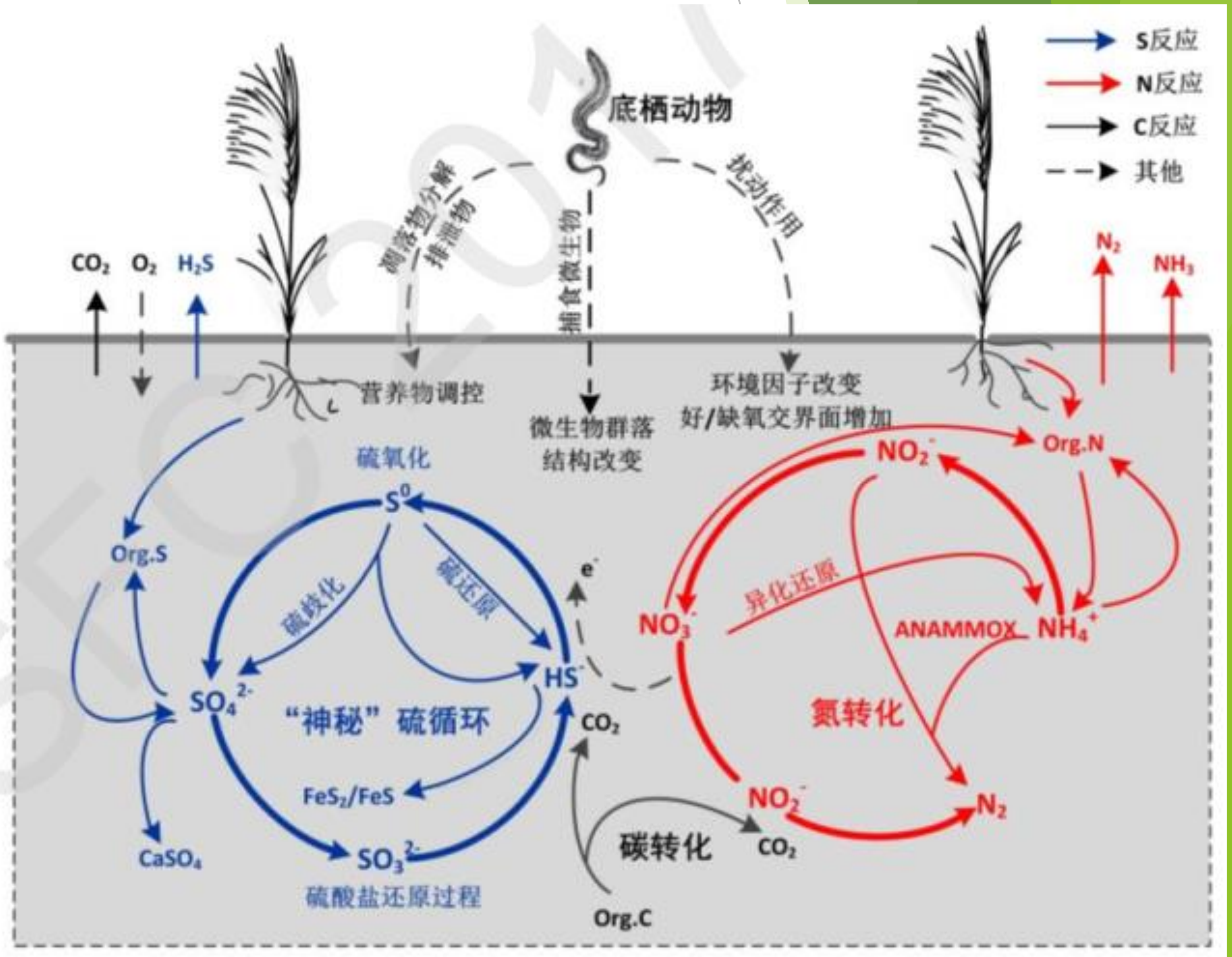
The Cycle of C, N, S in CWs

- The pathways of C, N, S cycle in CWs are very complex.
- Interactions among Micro-organisims, animals, plants, medias are still unclear



Greenhouse gas emission

- CO_2 emission FSW-CWs (96 mgC/m^2/h) < VSSF+HSSF-CWs (137mgC/m^2/h)
- CH_4 emission VSSF-CW (3.0 mgC/m^2/h)< FWS CWs (4.0 mgC/m^2/h) < HSSF CWs (6.4 mgC/m^2/h)
- N_2O emission no difference FSW-CW (0.09 mgN/m^2/h), VSSF-CW (0.12 mgN/m^2/h), HSSF-CW (0.13 mgN/m^2/h)
- Significant correlation TOC_{in} and CH_4 emission, TN_{in} and N_2O emission
- Hybrid CW can minimize GHG emission
- Future perspective
  - Identify sources of N_2O (nitrification or denitrification)
  - Analysis microbial community structure an functional gene responsible for GHG
  - Long-term investigation and process optimization to reduce the emission

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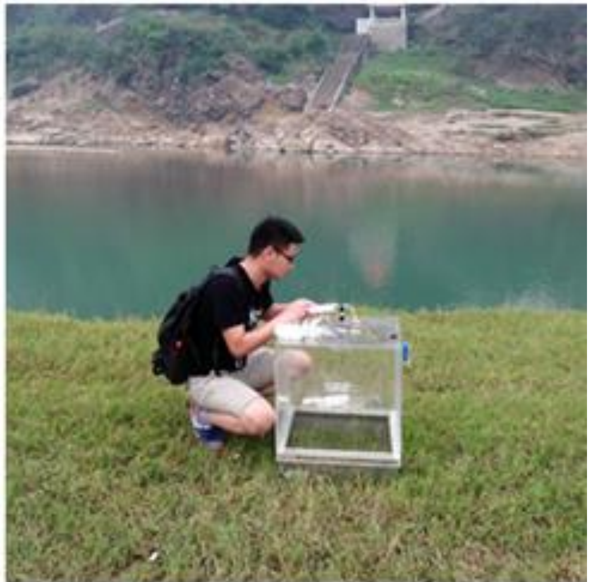
Mander et al., 2014

GHG (CH_4) control

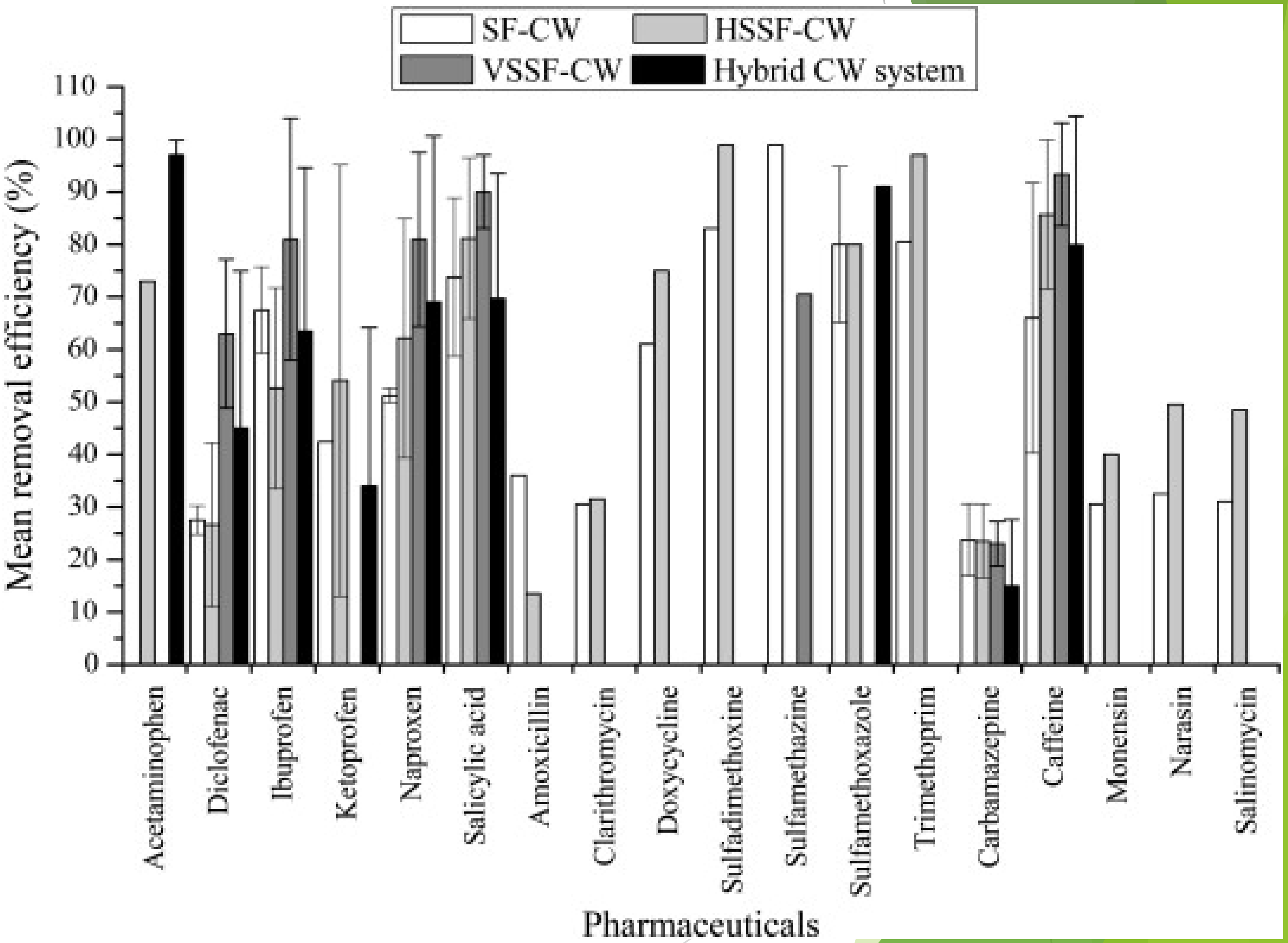
- Anaerobic Oxidation of Methane process is found in CWs
- We found ANME-2d in CW
- CH_4 emission was mitigated by dissimilatory metal reduction and anaerobic CH_4 oxidation



Lab-scale CW for CH_4 emission control

Pharmaceutic removal in CWs

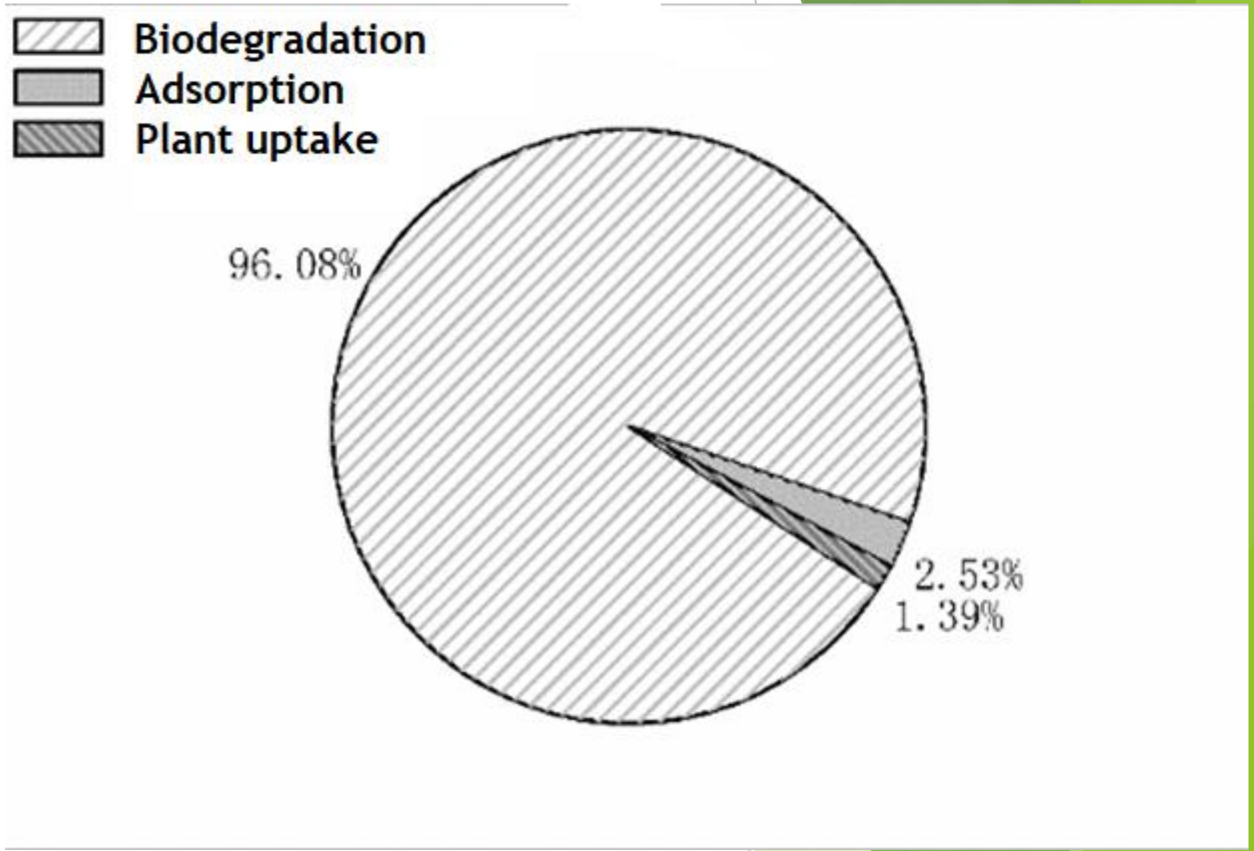
- Constructed wetlands show great potential for treatment of pharmaceuticals
- Substrate, plants and microbes in wetlands account for the removal mechanisms.
- Constructed wetlands do not completely reduce to low level the environmental risk due to pharmaceuticals in their effluent



Pharmaceutical removal in different CWs (Li et al., 2014)

Pharmaceutic removal in CWs

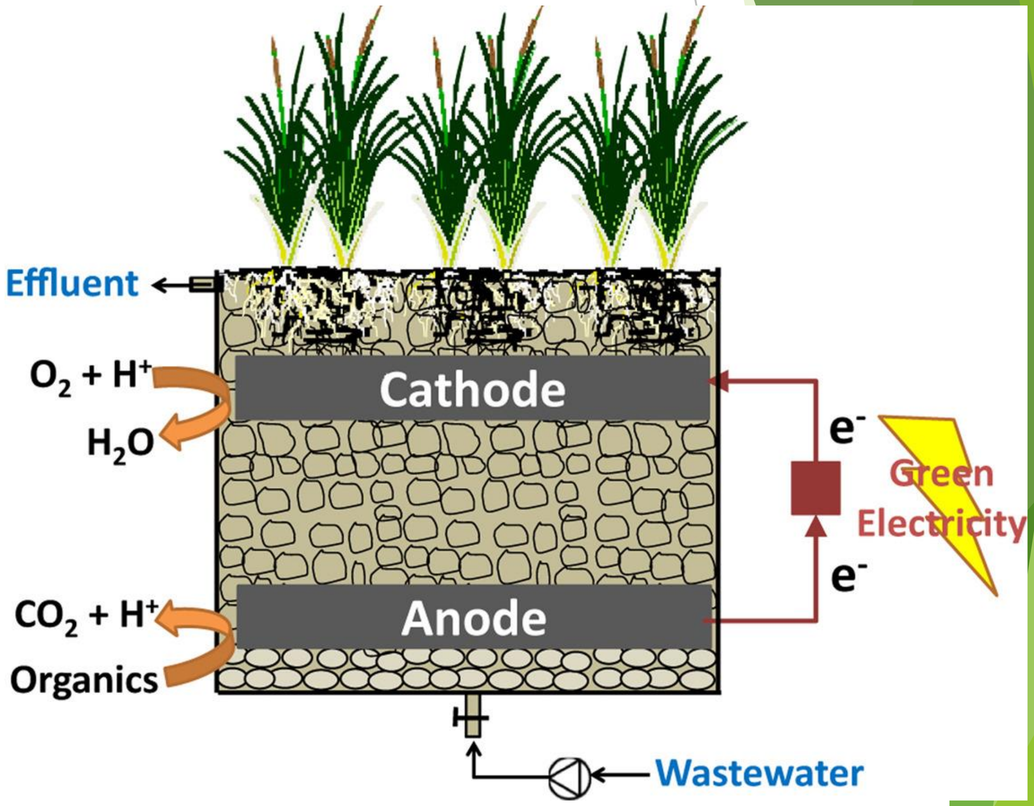
- Construction of vertical flow constructed wetlands and incorporation of aerated concrete blocks, gravel, natural manganese ore, natural iron ore in the CWs.
- Using carbamazepine and diclofenac as indicator drugs
- Anaerobic and aerobic reactors are connected in series to study the removal effect and mechanism



Diclofenac removal in Mn-mediated CW (Zhai et al., 2018)

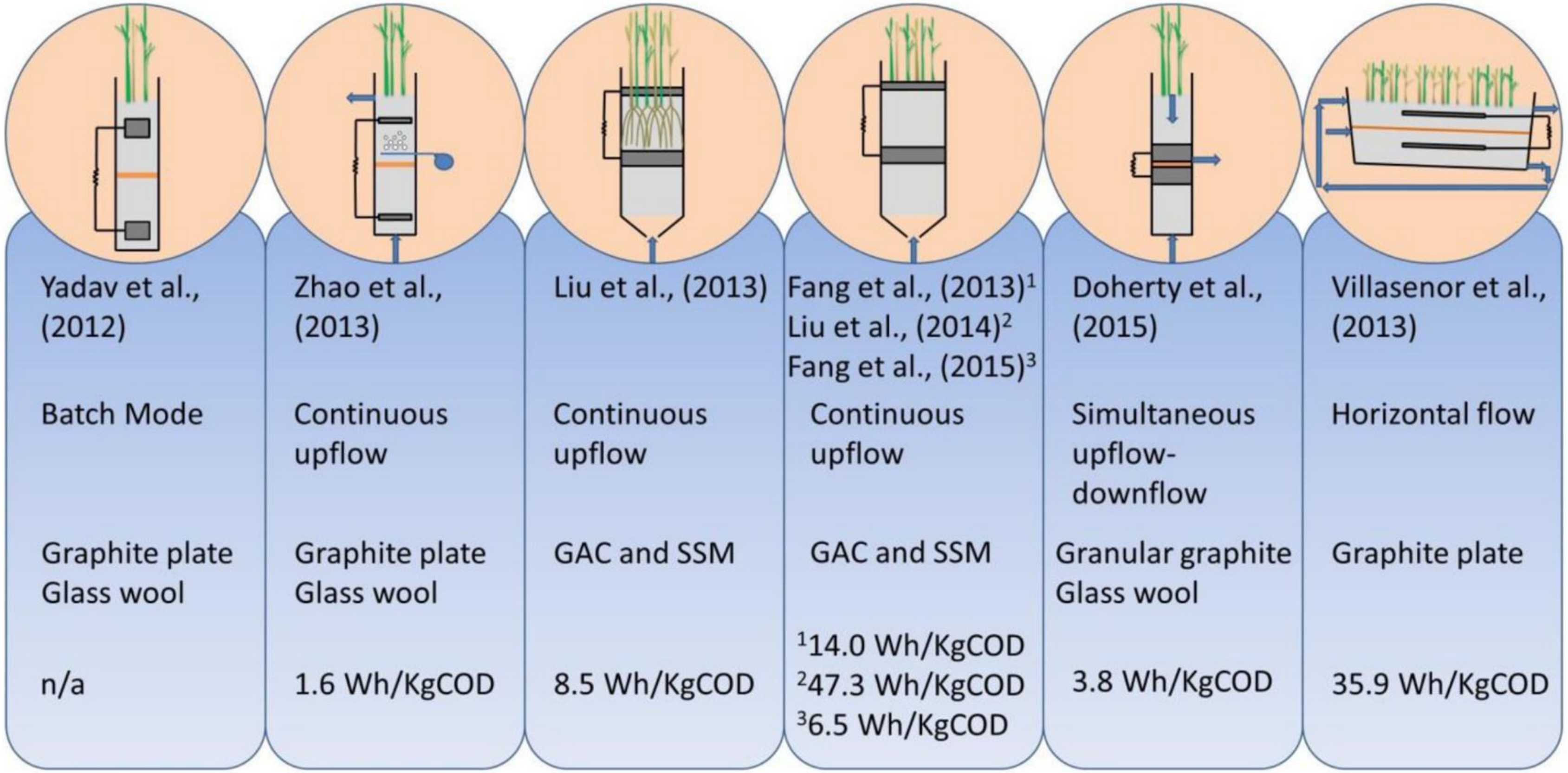
Harvesting electricity from CW-MFC

- CWs create the required redox gradient for MFC operation
- Electrogenic bacteria can degrade organics at anode and transfer the electrons to the cathode
- Maximum power density can reach about **44 mW/m²** with **95% COD** removal (Liu et al. 2014)
- System optimization is required



CW-MFC system (Doherty et al., 2015)

Harvesting electricity from CW-MFC



Different setups of constructed wetland-microbial fuel cells (Doherty et al., 2015)

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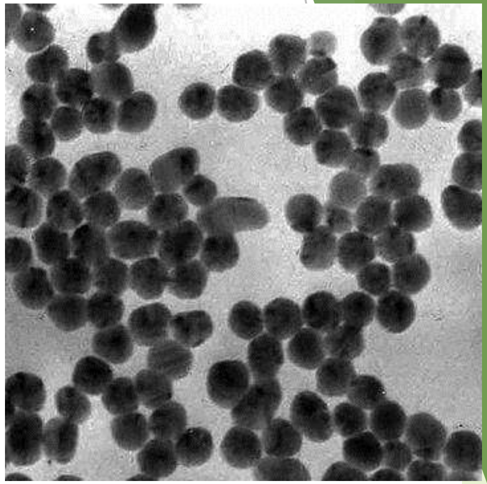
Micro-/Nano-particles

- Metallic engineered nanomaterials (ENMs)
  - Ag-NPs, Ti-NPs, ZnO-NPs
  - In wastewater, range from < 1 ng/L to 110 µg/L
  - Removal is low, mainly by aggregation and sedimentation, dissolution, sulfidation (Ag-NPs), adsorption, plant uptake
  - Effluent, harvested plant and waste sludge cause potential ENMs release
  - Future perspective on system malfunctions (short-circuiting), possible adverse effects CW released ENMs, etc.
- Micro-/Nano-plastic
  - No research investigate removal of microplastics in wetland
  - Affect the river and ocean ecosystems
  - CWs potentially remove microplastics via biodegradation (bacteria or earthworm), filteration, sedimentation, etc.
  - Further investigation is required



Ag nanoparticles

Microplastic

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(Auvinen et al., 2017; Talvitie et al., 2017; McCormick et al., 2014)

Thank you!