MELiSSA
MICRO-ECOLOGICAL LIFE SUPPORT SYSTEM ALTERNATIVE

CREATING A CIRCULAR FUTURE

Hydroponic nutrient solution monitoring for crop characterization

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SCOPE AND BACKGROUND

Crop characterization for MELiSSA Higher Plant Compartment

Plant Characterization Unit (PCU)

MELiSSA Pilot Plant (MPP)
Higher Plant Compartment (HPC)

Study, characterize and model growth and metabolism of higher plants

Crop characterization for MELiSSA Higher Plant Compartment

PaCMan project

- Engineer and manufacture a Plant Characterization Unit (PCU), *Italy*
  - Hydroponic research facility with closed atmospheric and liquid compartments

MPP COO6 project

- Upgrade the Higher Plant Compartment of MELiSSA Pilot Plant (MPP), *Spain*
  - Hydroponic facility, pilot plant scale
  - Upgrade air-tightness and hydroponic loop

Aims and limitations of presented work

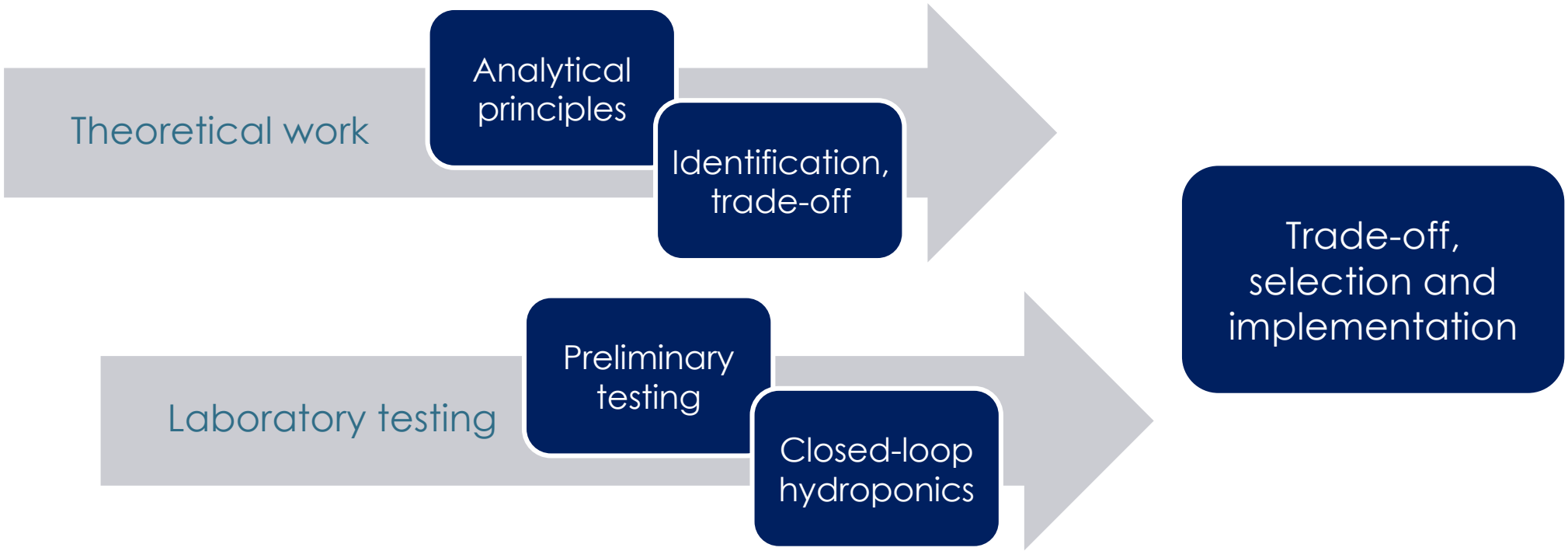
- **Detailed and real-time understanding of the dynamic water quality in hydroponics, for both advanced scientific insight and technical process control**

- Requirements
- Identify, (develop), test and select hardware
- Demonstrate pros/cons, potentials/challenges of analytical hardware as input to similar hydroponic systems
- Limitations
  - Selection of sensors/analyzers limited by several factors, budget, commercial availability, degree of automation, existing hardware, etc.
  - Not an exhaustive test of available hardware, not a comparison between manufacturers

REQUIREMENTS FOR REAL-TIME MONITORING OF CHEMICAL WATER QUALITY

Parameter	PCU	MPP HPC
pH (Redundancy, used for control)	Mandatory	Mandatory
Conductivity (Redundancy, used for control)	Mandatory	Mandatory
Temperature	Mandatory	Mandatory
Dissolved O_2	Mandatory	Mandatory
Dissolved CO_2	Mandatory	Not required
Macronutrients (N as NO_3^- and NH_4^+, K, Ca, Mg, S, P)	Wish-list, priority 1	Priority 1: NO_3^- Priority 2: NH_4^+, K^+
Micronutrients (Cl, Na, Mn, B, Zn, Cu, Fe, Mo)	Wish-list, priority 2	Not prioritized

IDENTIFICATION, TESTING AND SELECTION OF HARDWARE


Theoretical work
Analytical principles
Identification, trade-off
Laboratory testing
Preliminary testing
Closed-loop hydroponics
Trade-off, selection and implementation

Conductivity

Contacting — Mettler Toledo, In-Situ

Inductive — Mettler Toledo, Endress+Hauser

Dissolved O_2

Amperometric — Mettler Toledo

Optical — Mettler Toledo, In-Situ, Hamilton, Endress+Hauser

pH

Glass electrode (electrochemical) — Endress+Hauser, Hamilton, Mettler Toledo

T

Integrated in conductivity, pH

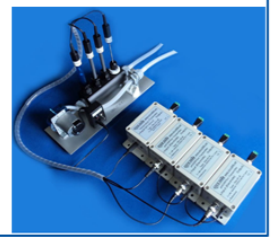
Dissolved CO_2

Optical — Labolytic

Nutrients

Optical — Endress+Hauser

Ion specific electrodes — CleanGrow, Nico, In-Situ, Endress+Hauser

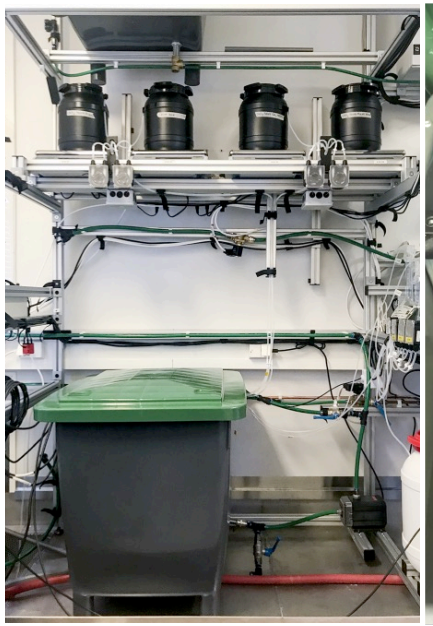


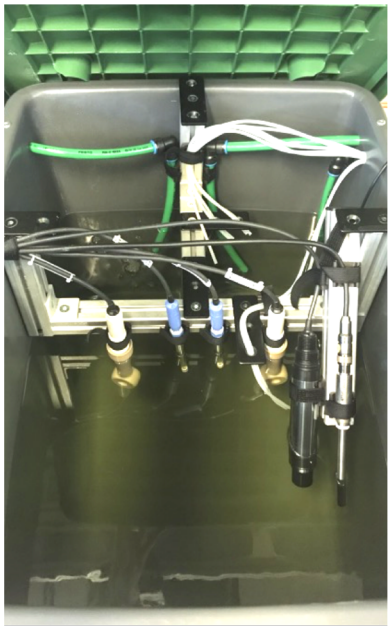
Other analytical principles and numerous units identified, theoretically evaluated, but not selected for lab testing due to e.g. budget, and priorities

Evaluation of analytical hardware for nutrients still in progress, including commercially available high-end analyzers

Hydroponic test bed

- Lettuce cultivation in closed-loop system
- Nutrient Flow Technique and Deep Water Culture
- Sensors installed in nutrient solution tank or at-line





Analytical technology for monitoring hydroponic water quality

pH, conductivity and temperature

- Generally, limited differences between manufacturers and units (with some exceptions)

pH (glass electrodes)

- Best electrodes: Accuracies well within ± 0.05 pH, ± 0.10 even after 5 weeks without maintenance and high algae loads

Temperature

- Integrated in pH and conductivity
- Typically well within ± 0.3 °C

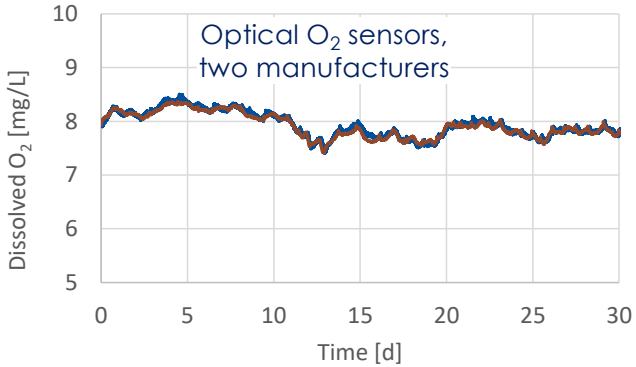
Conductivity (inductive and contacting)

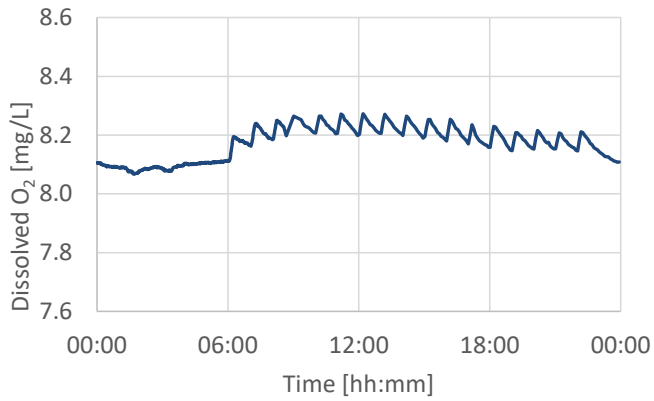
- Best electrodes: Accuracies typically within ± 0.02 mS/cm
- High accuracies by inductive sensors even after several weeks without maintenance
- Contacting sensors required more frequent washing and recalibration

Dissolved O_2 and CO_2

Dissolved O_2

- Optical sensors outcompeted amperometric with respect to accuracy and user friendliness (limited dataset)
- Examples after 5 weeks, no maintenance:
  - Amp. ± 1.0 mg/l
  - Optical ± 0.1 mg/L

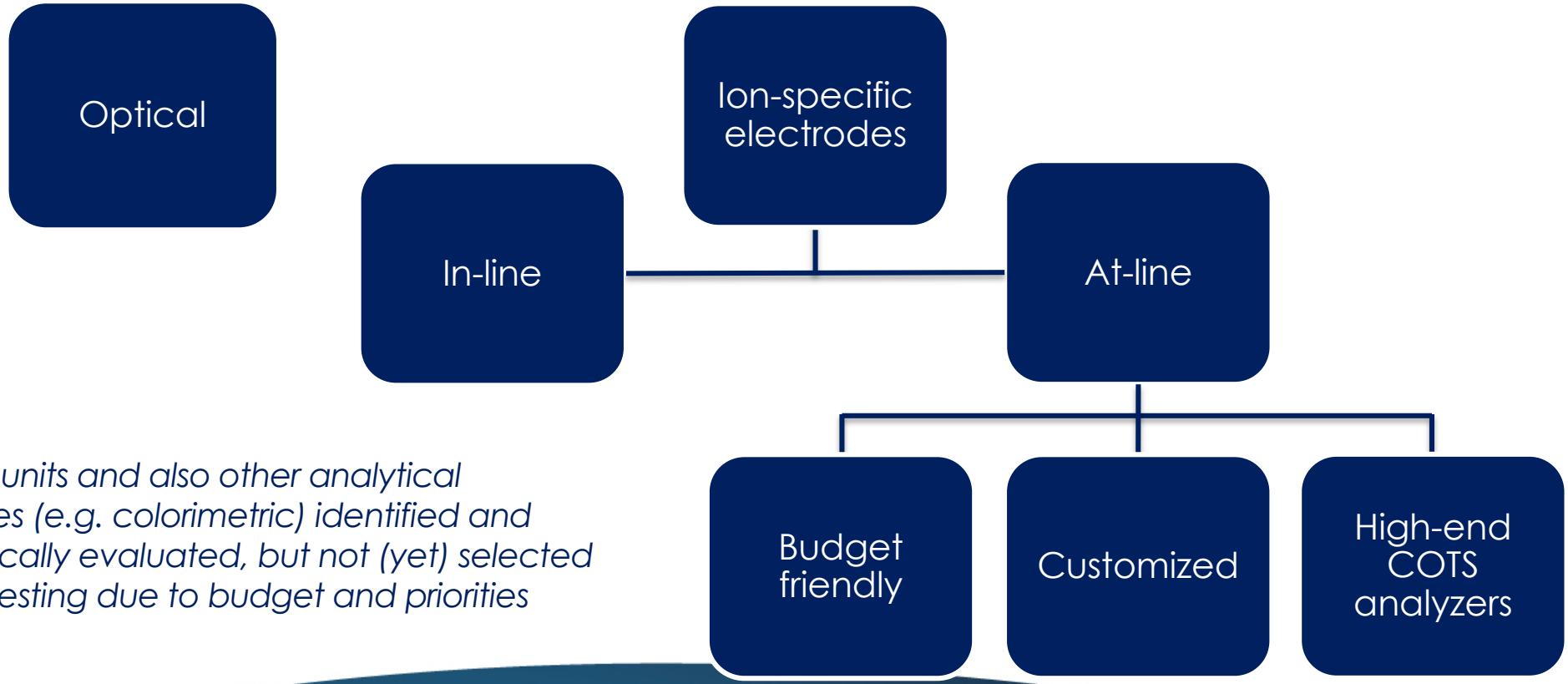




Dissolved CO_2 (optical)

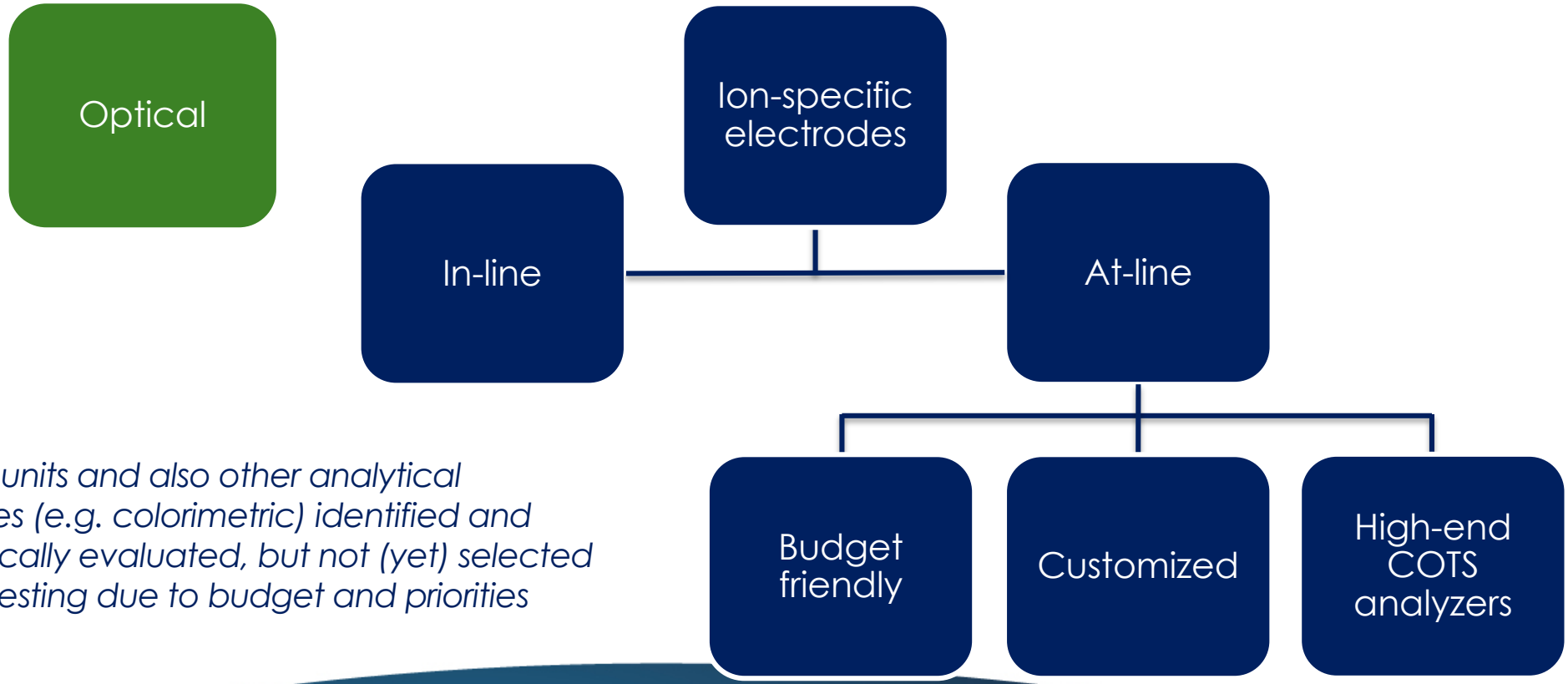
- Long stabilization time
- Accuracies typically within ± 5 % (5 weeks without maintenance)

Nutrients



Several units and also other analytical principles (e.g. colorimetric) identified and theoretically evaluated, but not (yet) selected for lab testing due to budget and priorities

Nutrients

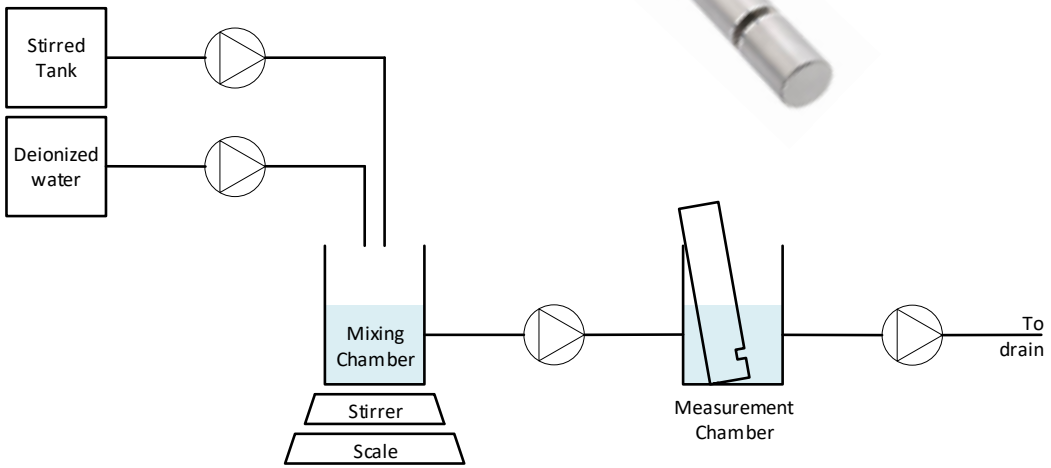


Several units and also other analytical principles (e.g. colorimetric) identified and theoretically evaluated, but not (yet) selected for lab testing due to budget and priorities

Optical NO_3^- (NO_x^-)

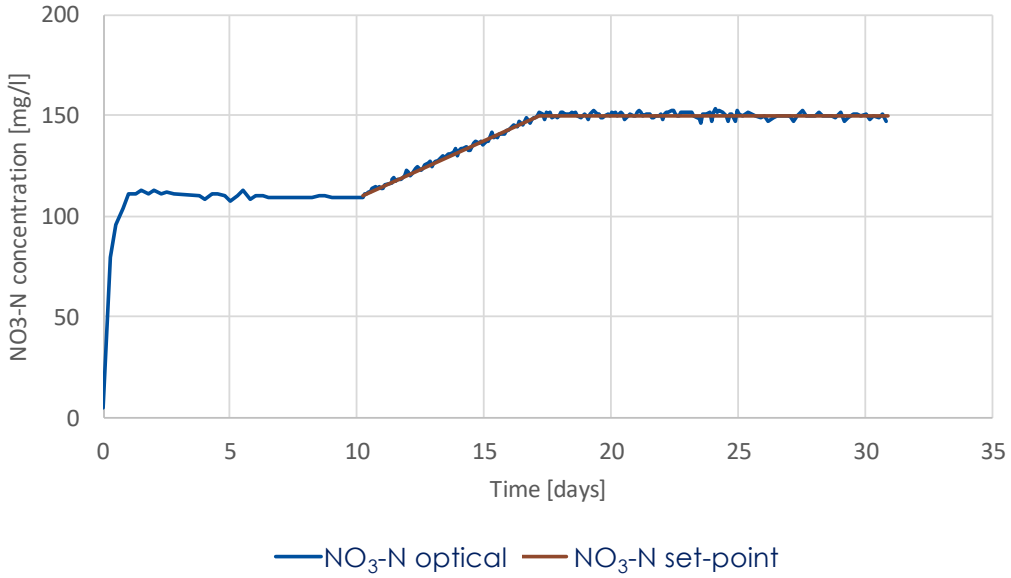
- Endress+Hauser CAS51D, measures both nitrate and nitrite
  - Typically negligible levels of nitrite in hydroponics
- Excellent response-time, selectivity, high accuracy
- High price and needs dilution (1:20 – 1:50)

- Breadboard set-up
  - Auto-sampling, auto-dilution system
  - 256 control measurements over a 30-day hydroponic run: 98 % of measurements within ± 2 % m.v.



Optical NO_3^- (NO_x^-)

- Accurate NO_3^- monitoring each 2-6 hours made possible automatic control of NO_3^-
  - Day 0 – 10: Conductivity set-point
  - Day 10 – 17: NO_3^- set-point (increasing)
  - Day 17 – 31: NO_3^- set-point (constant)
  - Monitoring confirmed with offline measurements (± 5 % m.v.)



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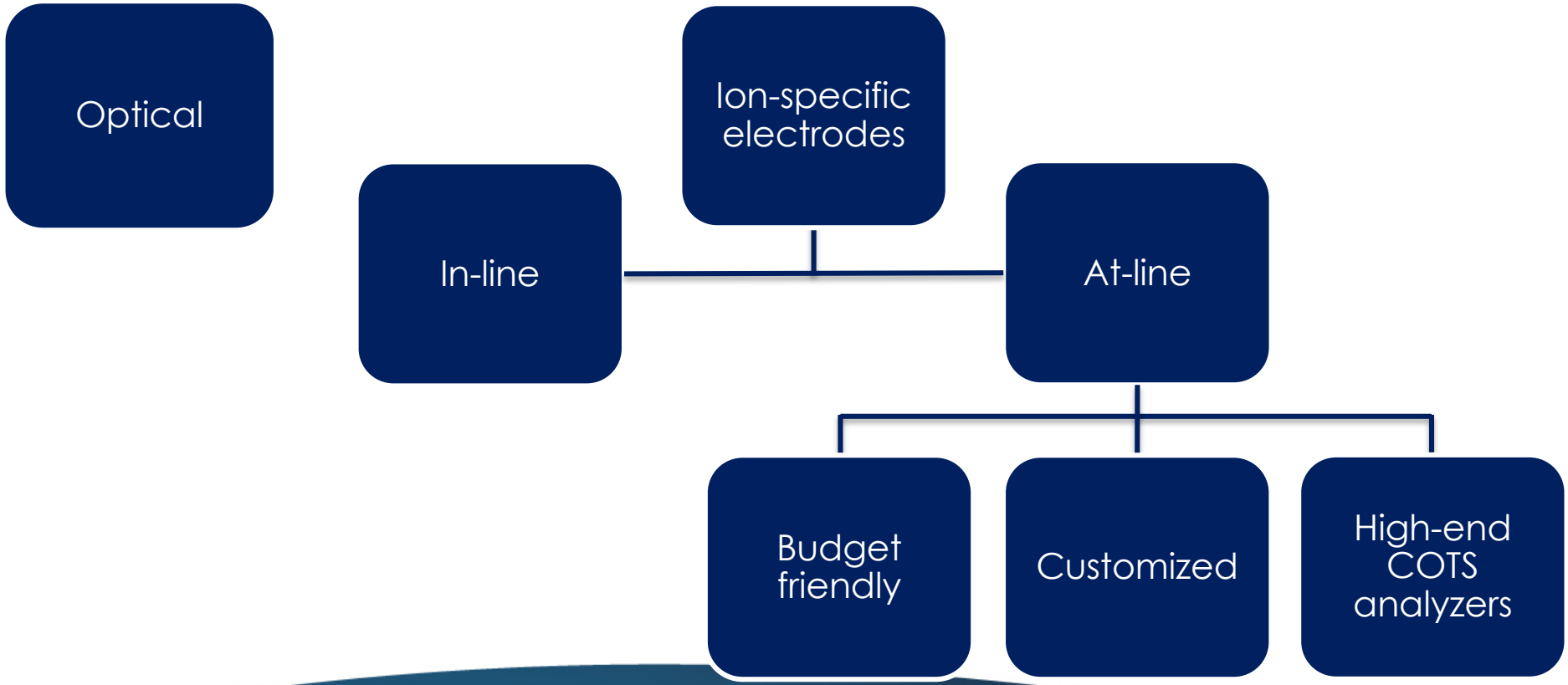
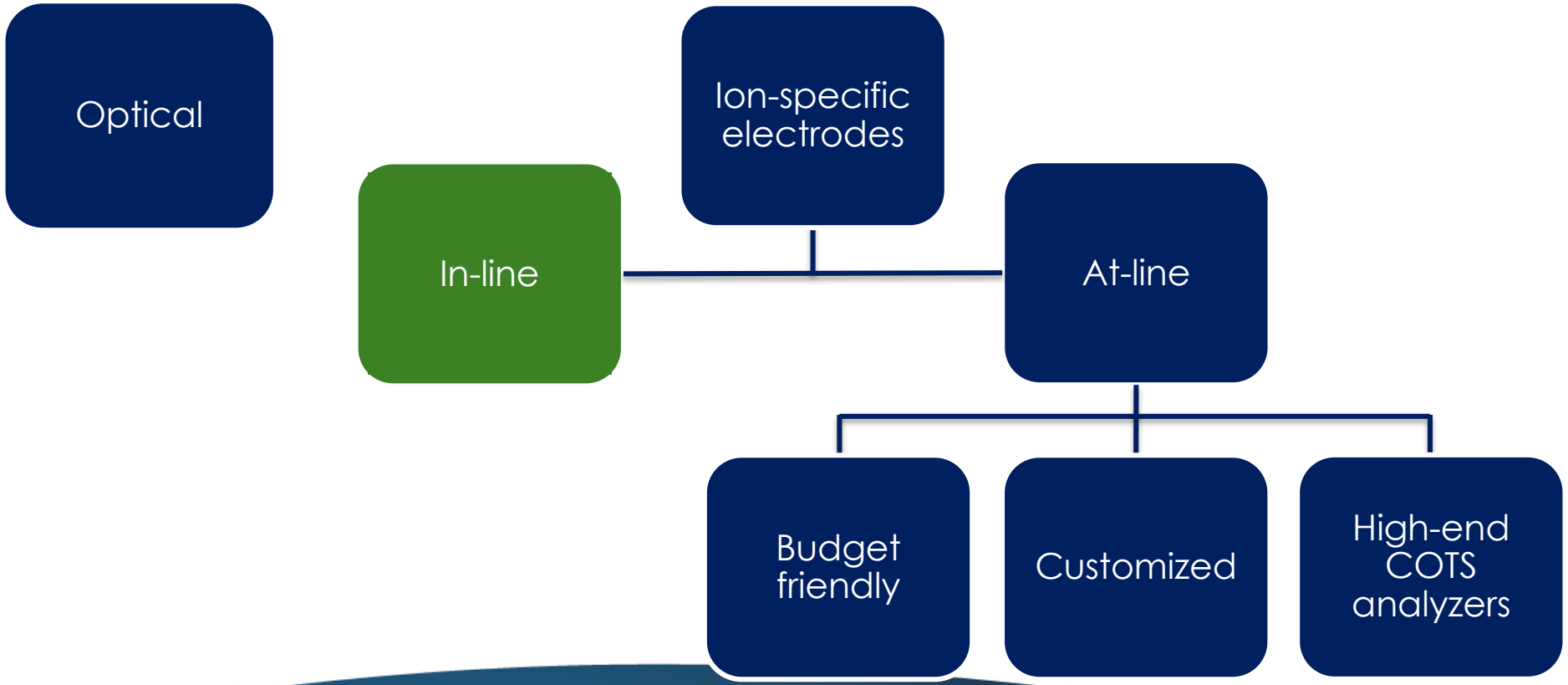

Optical
Ion-specific electrodes
In-line
At-line
Budget friendly
Customized
High-end COTS analyzers

Nutrients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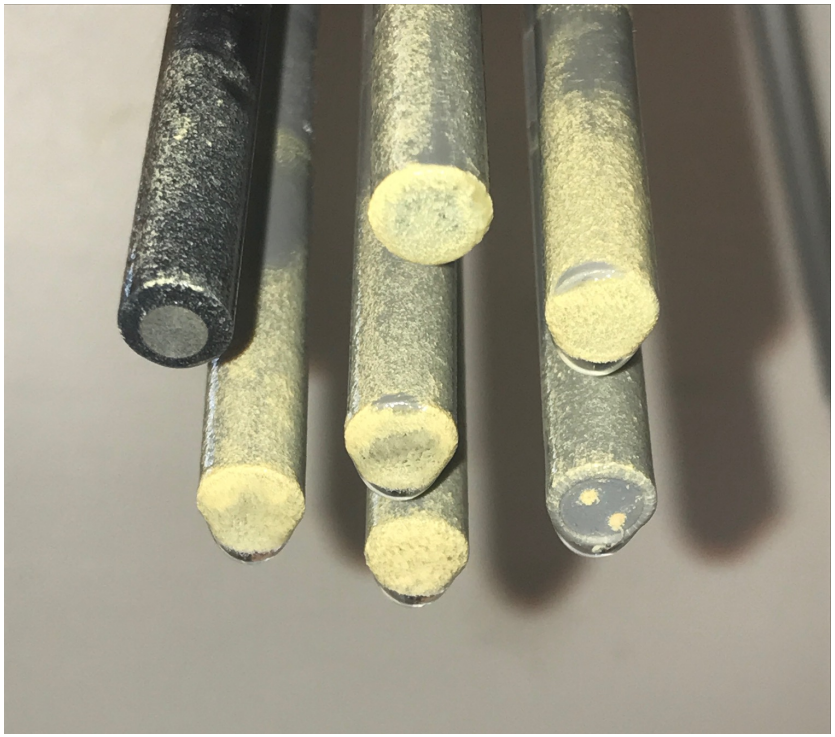
In-line monitoring of nutrients

- Drift and biofouling of ISEs
- Frequent washing and/or recalibration required



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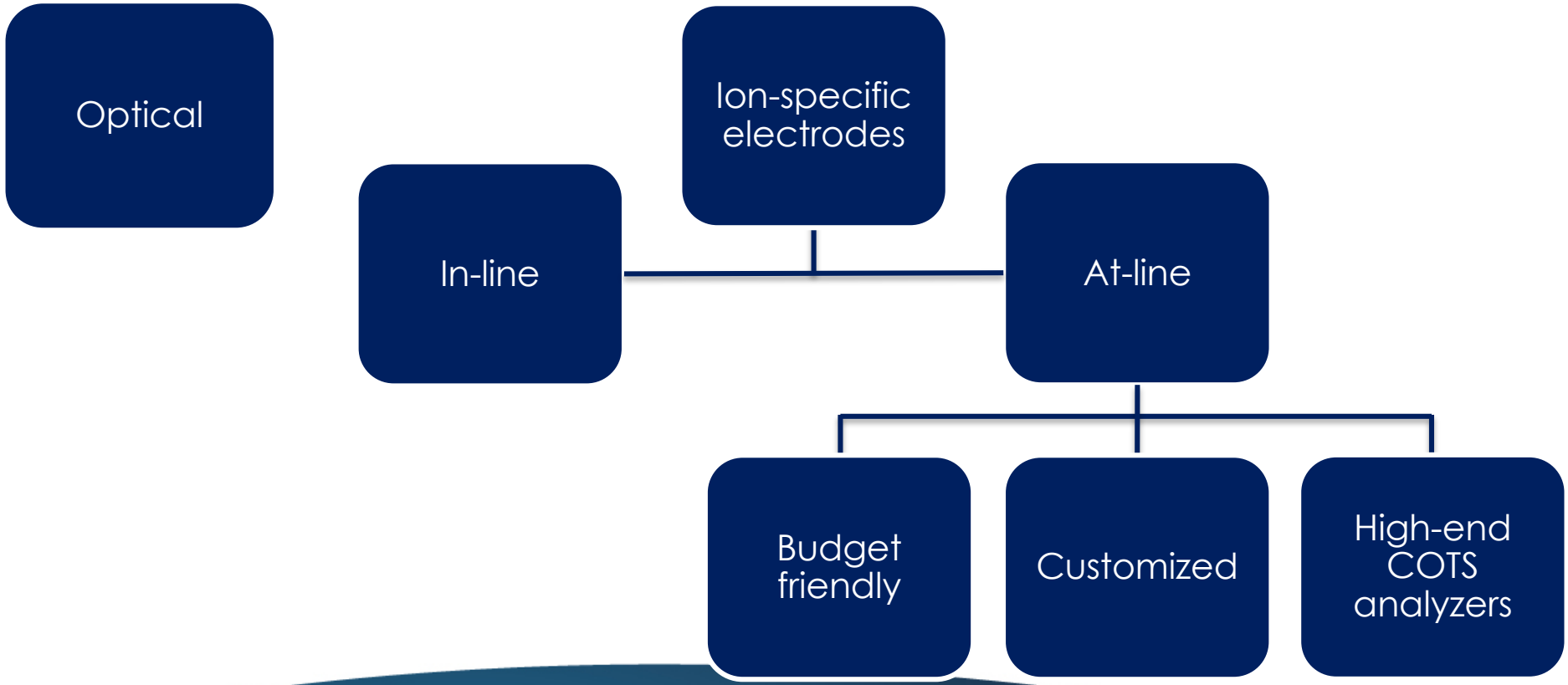
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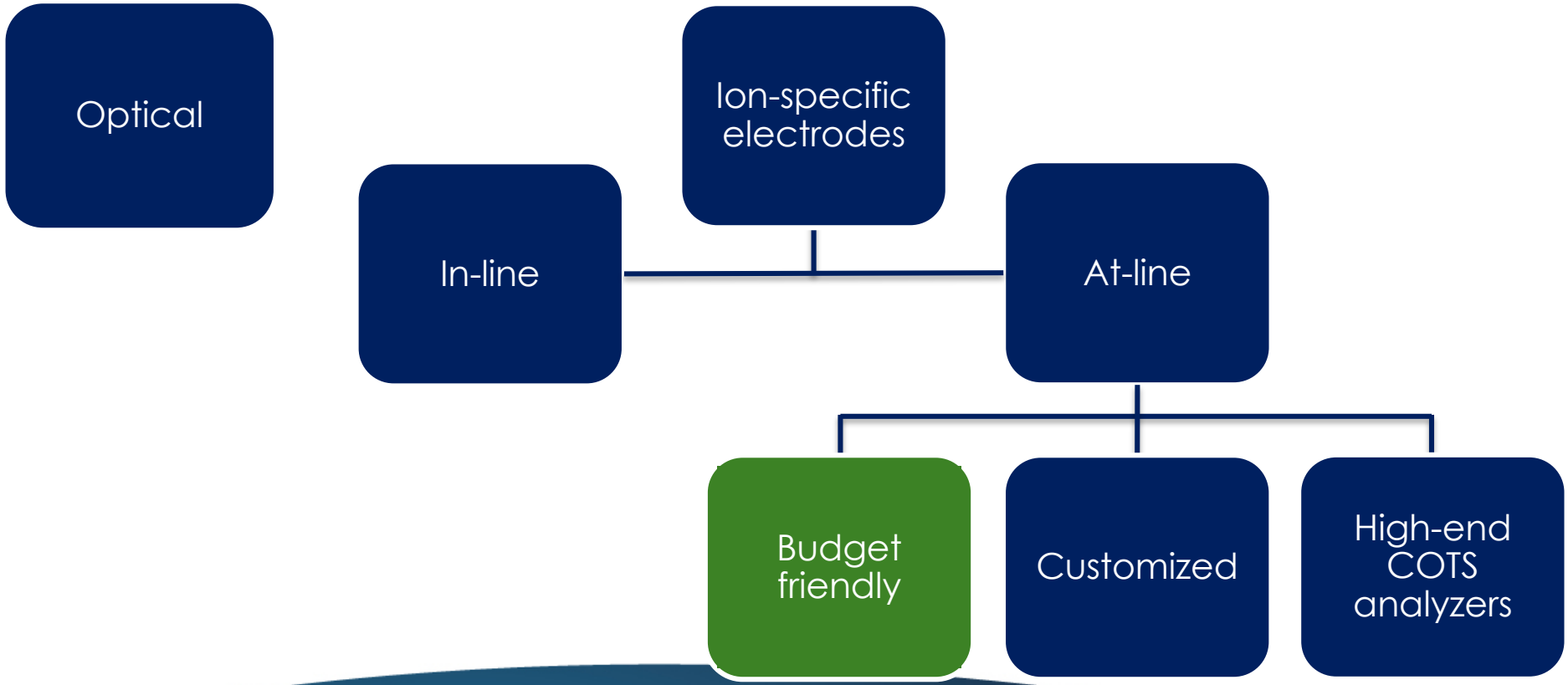
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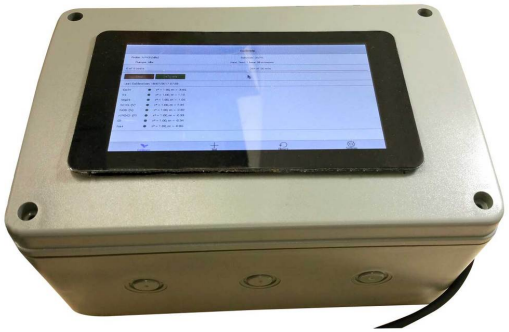
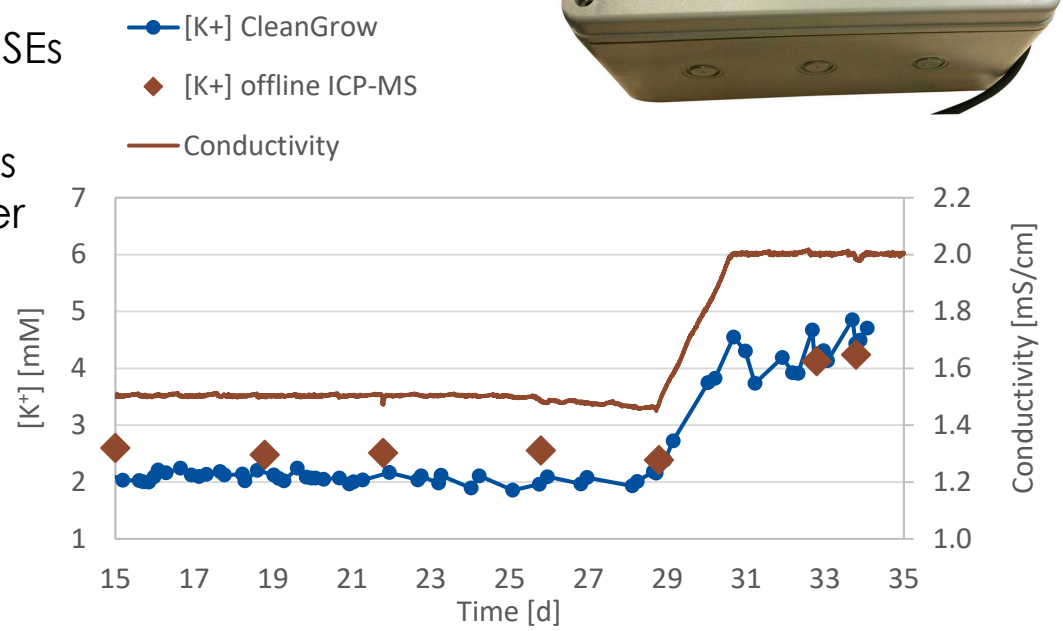
CleanGrow multi-ion analyzer

- ISEs: NH_4^+, NO_3^-, Ca^{2+}, K^+, Na^+, Cl^-, Mg^{2+}, HPO_4^{2-}
- Developed for hydroponics
- Auto-calibration abolishes ISE drift
- During hydroponic runs, accuracy of some ISEs was typically within ± 20 %
- Other ISEs and general reproducibility seems affected by reduced ISE responsiveness over time (possible fouling of ISEs)





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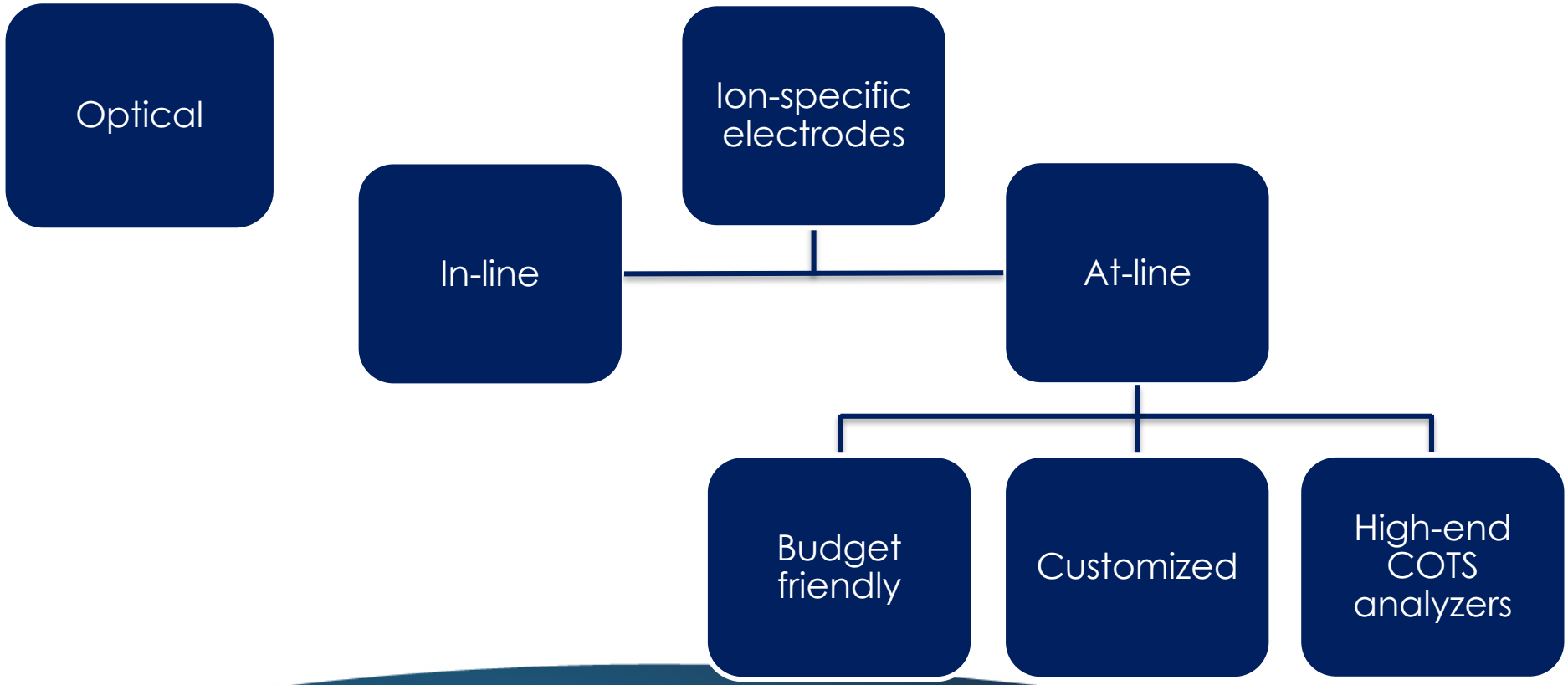
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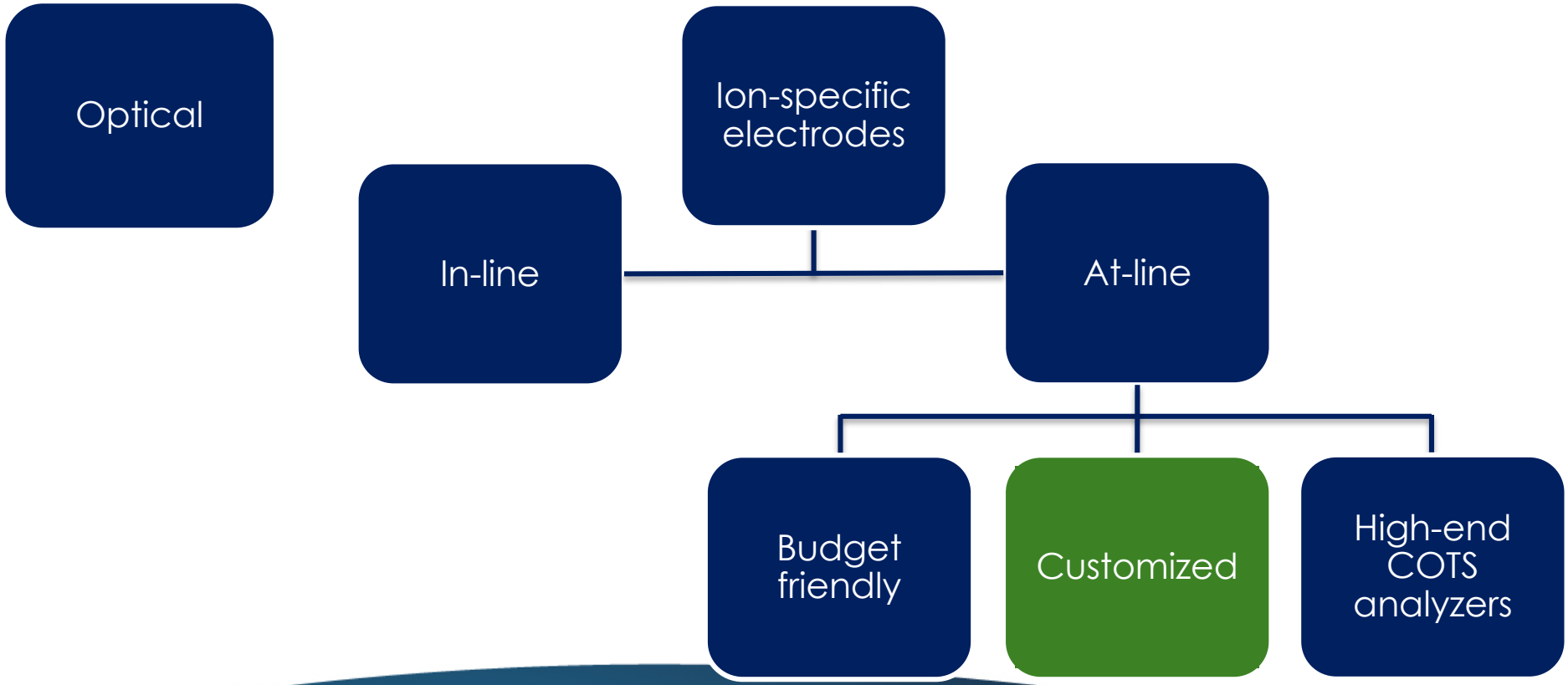
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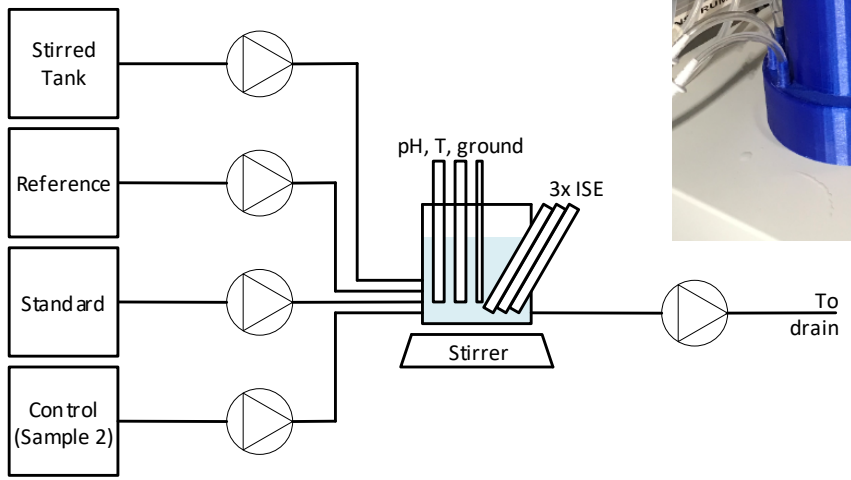
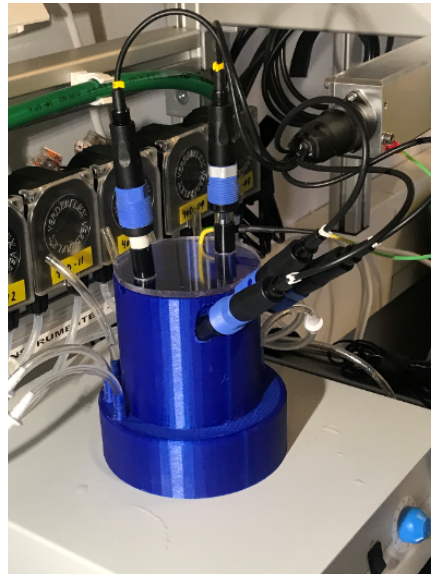
Reconfiguration and automation of COTS ISEs

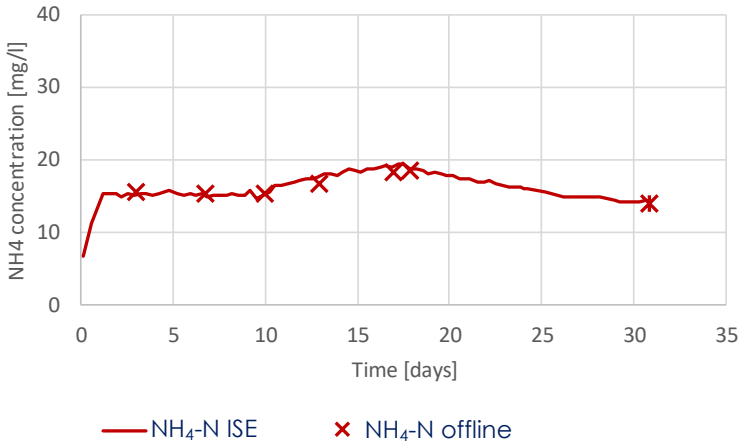
- Endress+Hauser ISEs for CAS40D: NH_4^+, NO_3^-, K^+
- In-line sensor reconfigured for at-line strategy
- Development of auto-sampling and auto-calibration functionality

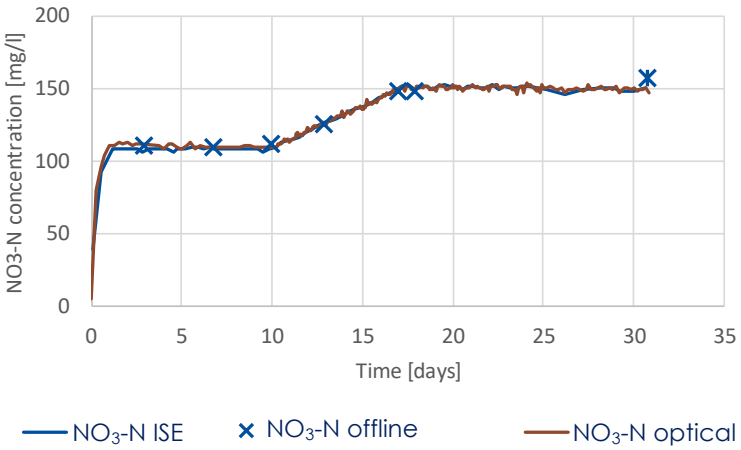


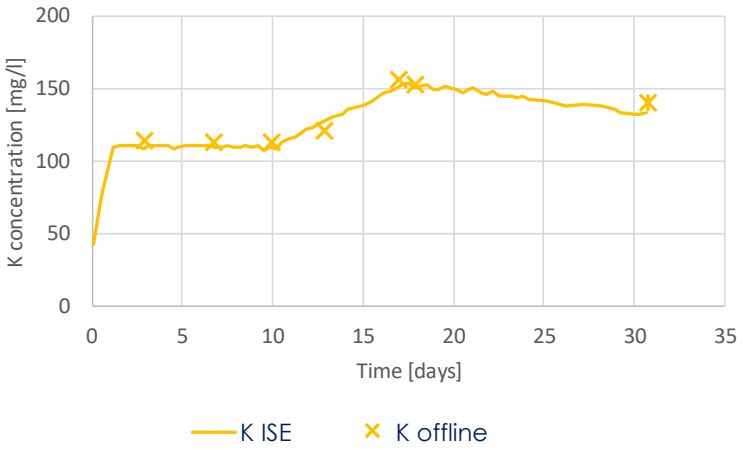


Reconfiguration and automation of COTS ISEs

- Control measurements of known solutions during 30-days hydroponic run:
  - NO_3^- and K^+: 95% of measurements deviated < 1.5%
  - NH_4^+: All measurements deviated < 2 mg/l
- Monitoring confirmed with offline measurements (± 5 % m.v.)







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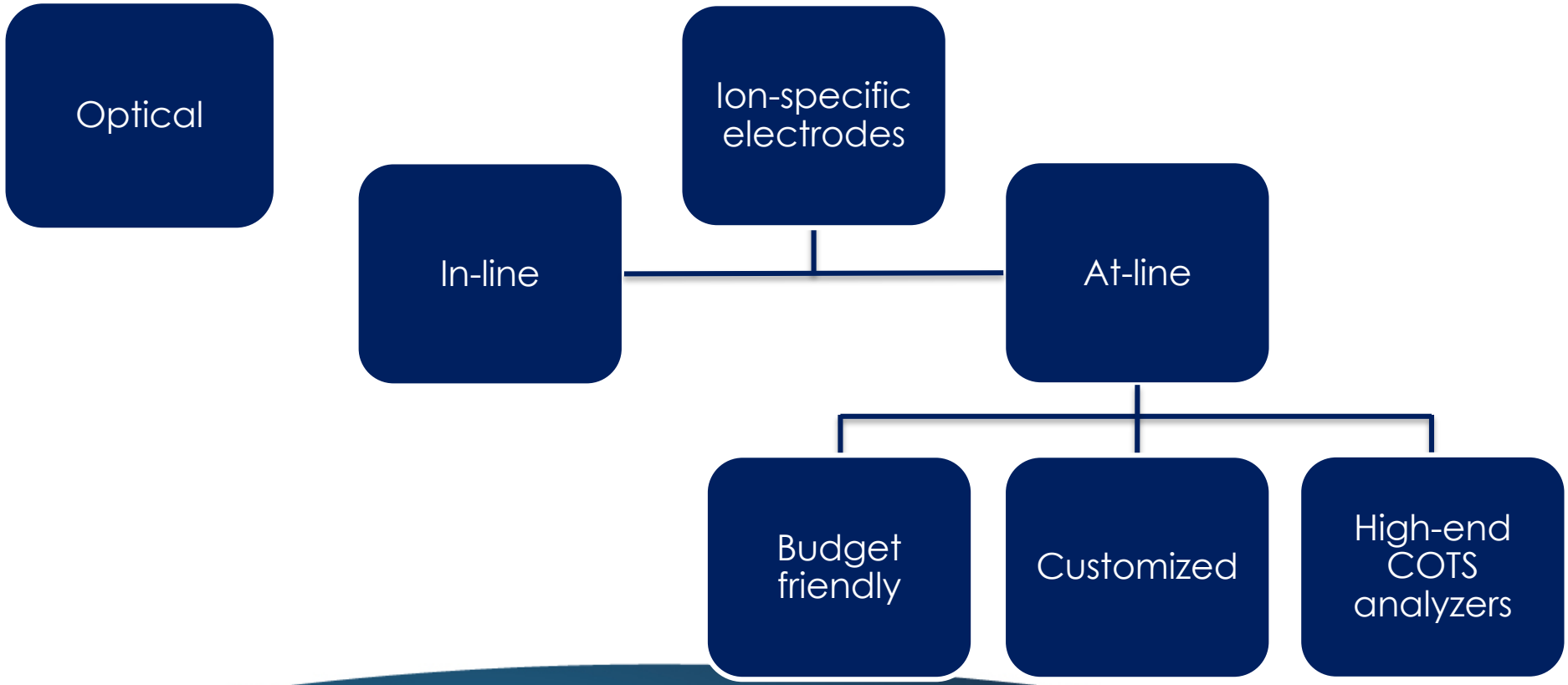
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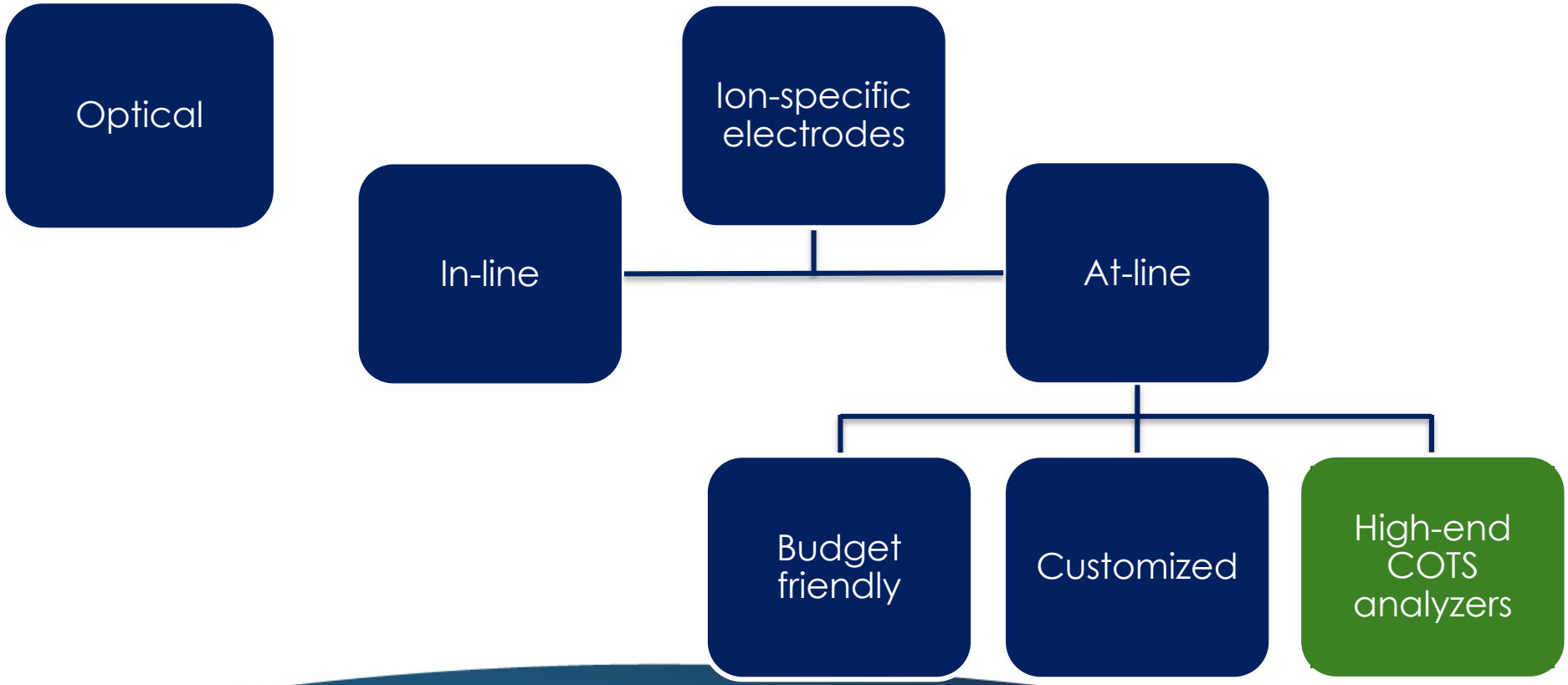
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High-end COTS analyzers

- Towards more mature technology maturity, with high accuracy
- At-line analyzers, higher costs
- ISE, optical, colorimetric, etc.

- *Work in progress in collaboration with UAB/MPP*

SUMMARY

Compliance with requirements

Parameter	PCU	MPP HPC	
pH	Mandatory ✓	Mandatory ✓	Endress+Hauser CPS11D (PCU) Hamilton Easyferm Plus ARC (MPP)
Conductivity	Mandatory ✓	Mandatory ✓	Endress+Hauser CLS50D
Temperature	Mandatory ✓	Mandatory ✓	*Integrated in pH/conductivity*
Dissolved O_2	Mandatory ✓	Mandatory	Mettler Toledo InPro 6860i (PCU) Hamilton Visiferm DO ARC (MPP)
Dissolved CO_2	Mandatory ✓	Not required ✓	Labolytic optical CO_2
Macronutrients	Wish-list, priority 1 ✓	Priority 1: NO_3^- Priority 2: NH_4^+, K	Endress+Hauser CAS51D (PCU) CleanGrow Auto CG200 (PCU)
Micronutrients)	Wish-list, priority 2 ✓	Not prioritized	CleanGrow Auto CG200 (PCU)

Accurate breadboards COTS in progress

Conclusions

- pH, conductivity and dissolved gas
  - Mature technologies offer high accuracy, long term monitoring
  - Our recommendation is inductive sensors for conductivity and optical sensors for dissolved gas
- Nutrients
  - Main challenges for real-time, long-term monitoring include drift, selectivity, biofouling
  - Our recommendation is at-line implementation
  - High accuracy monitoring and control of NO_3^- (optical sensor, requires dilution)
  - High accuracy monitoring of NO_3^-, NH_4^+ and K^+ (customized, based on ISE)
  - Mature tech. for nutrient monitoring available, but higher cost (typically 20 – 50 KEUR)

Acknowledgements

- Fruitful collaboration with PaCMan and MPP COO6 project partners, and ESA-ESTEC
  - **UAB/MPP** (MPP COO6 coordinator), including E.E. Peiro Cezon, C. Arnau Jimenez, D. Garcia Gragera, and F. Gòdia Casablancas
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THANK YOU.

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