Advanced Methods for Condition Monitoring and Control of Large Engines in Maritime Applications

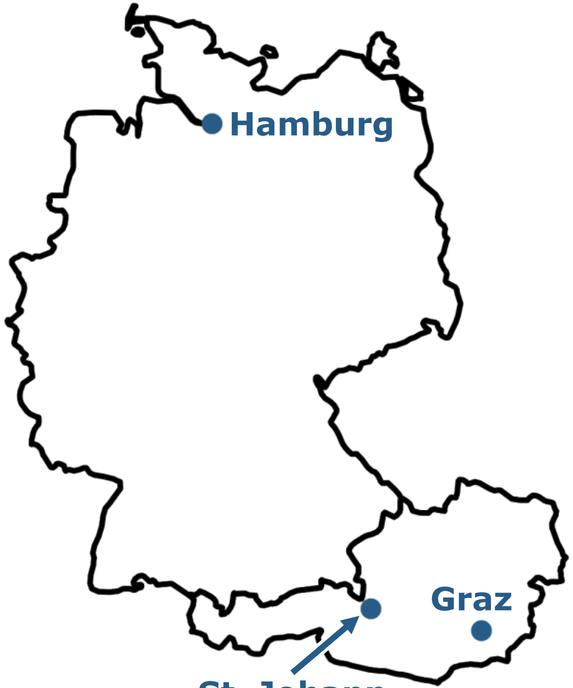
June 25, 2026 • Christian Laubichler

Let’s Start With Some History…

…My History with Hamburg

When I think of Hamburg, this is what I picture*:

Queen Elizabeth 2 (QE2)
Maiden call in Hamburg (1972)



* A picture hanging in my grandmother’s kitchen, who grew up in Hamburg

Let’s Start With Some History…

…On the Queen Elizabeth 2 (QE2)

- **QE2 facts** (just a few)
  - British transatlantic ocean liner (Cunard Line)
  - In service 1969–2008
  - 70,327 GT | 293.5 m long | 32.1 m wide
  - Service speed ~28–32 knots
  - Engine room
    - Originally steam turbine powerplant
    - Refit 1986/87 to diesel electric with 9 medium-speed engines (95.6 MW in total)
  - Sophisticated alarm and monitoring system

- **What has changed since the QE2 era in condition monitoring?**
  - Rise of artificial intelligence (AI) and machine learning (ML)
  - Emergence of edge computing for decentralized, real-time processing

Condition Monitoring of Large Engines

Where Does Artificial Intelligence Fit In?

Condition monitoring process

Condition detection → Condition comparison → Diagnosis

Virtual sensors

Digital twins
Large language models

Reference models

Anomaly detection

Early failure indicators

Fault

Key message:
Many opportunities for **A**rtificial **I**ntelligence and **M**achine **L**earning

Wear/damage compensation

Control system

Model predictive control
Parameter tuning
Model-free ML control

Preventive & condition-based

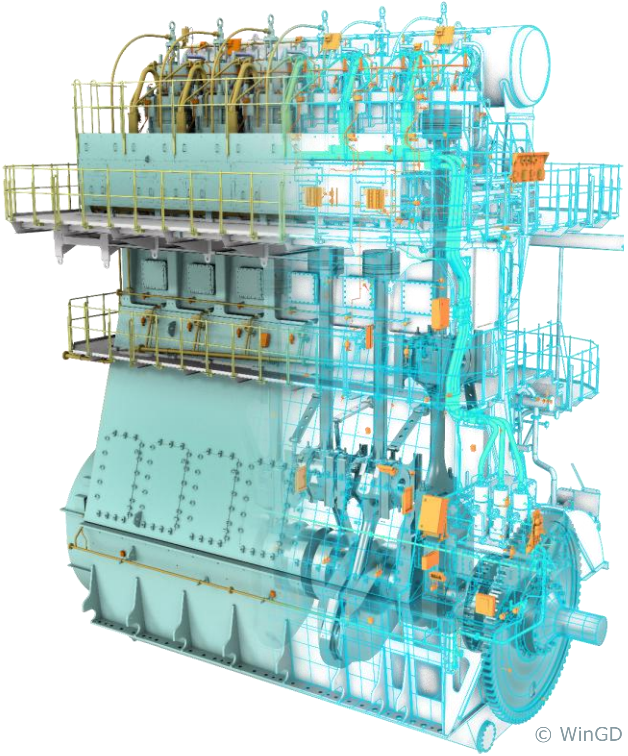
Corrective

Maintenance

Remaining useful life prediction
Optimal maintenance scheduling

Condition Monitoring of Large Engines

Condition Monitoring Systems



- **Engine level systems**
  - Typically provided by engine manufacturer/designer
  - Instrumentation of entire engine measuring, e.g.,
    - Engine speed
    - Engine load
    - Cylinder pressures
    - Bearing temperatures
    - Fuel mode
    - Injection settings
    - Valve timings
  - Contextual data on navigation, weather, etc.
  - Standalone platforms offered for data analytics

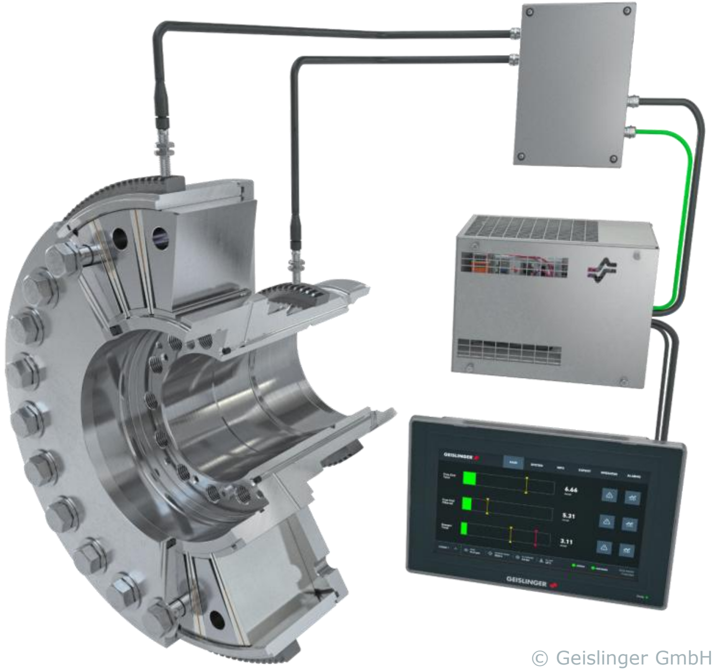
Condition Monitoring of Large Engines

Condition Monitoring Systems

- **Component level systems**
  - Typically provided by component manufacturer
  - Component-specific instrumentation
    - Standalone system with local focus
    - No engine level data access/input
    - Operational context information partly detectable
  - Components can become "intelligent" through

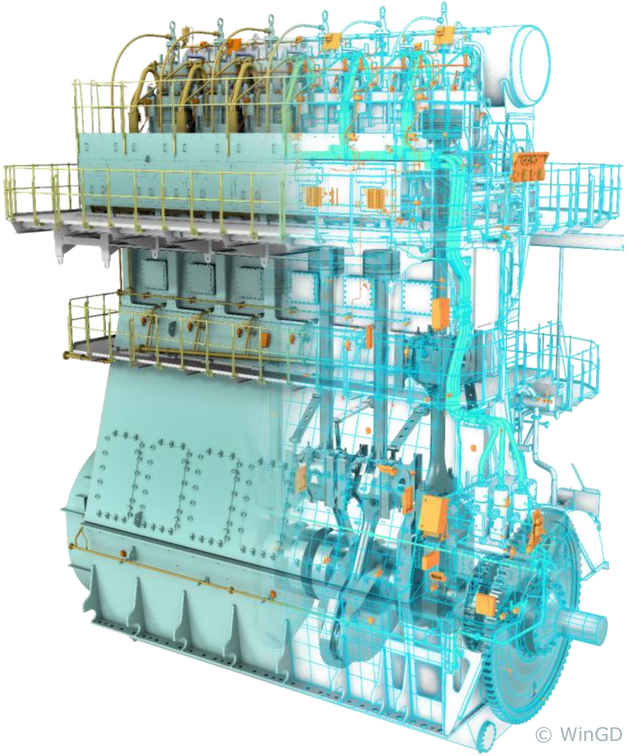
    Advanced instrumentation + Data analytics (AI/ML) → Value-added data (VAD)

  - Standalone platforms offered for data analytics



Condition Monitoring of Large Engines

How to Benefit From Both Engine and Component Level?



© WinGD

Data sharing

Intelligent component VAD

←

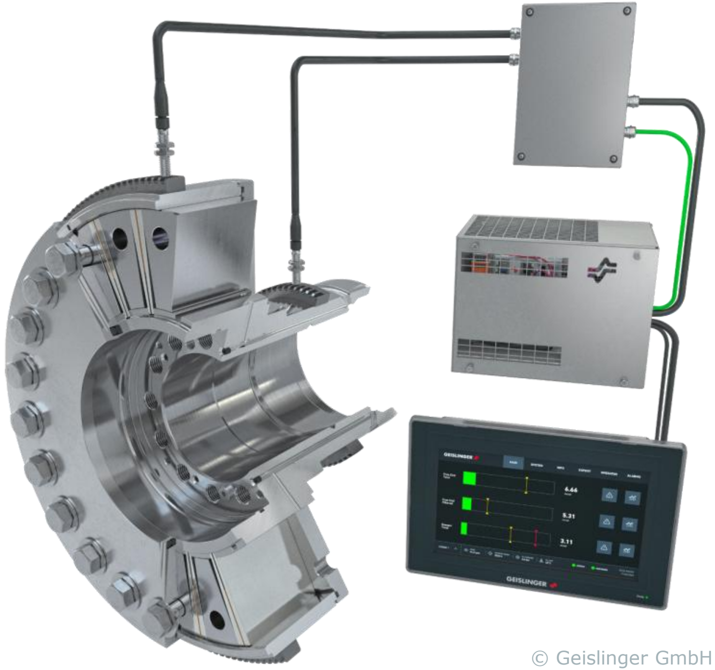
→

Engine operation and contextual data

Scenarios

Permanent data sharing

Learn self-contextualization



© Geislinger GmbH

Advanced CM of Large Engines

How to Start Such an Endeavor?

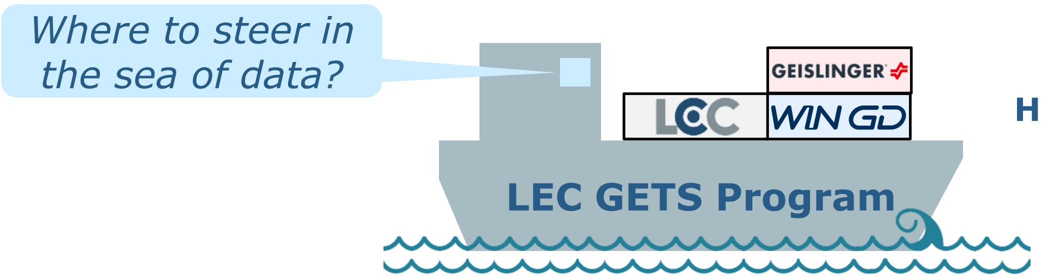
Engine level

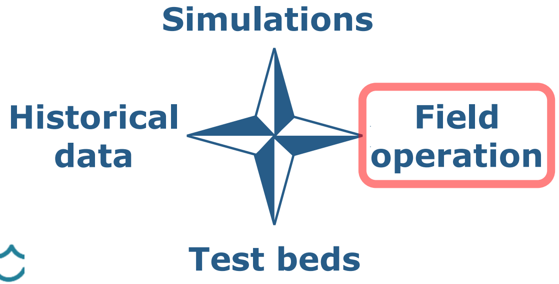
- Large two-stroke low-speed engines by WinGD
- Fuel types: LNG, Diesel, NH_3, MeOH, EtOH, LPG
- WinGD Integrated Digital Expert (WiDE) providing
  - Engine data monitoring, diagnostics and troubleshooting capabilities
  - Onboard and offshore support

Component level

- Torsional vibration (TV) dampers by GEISLINGER
- Mounted at crankshaft free end
- Geislinger monitoring system (GMS) providing
  - Continuous acquisition and
  - Evaluation of torsional vibrations

} Intelligent TV damper



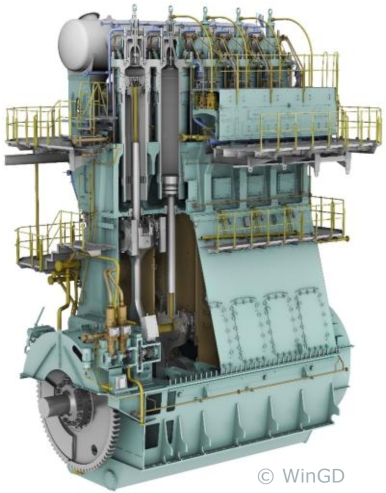


Advanced CM of Large Engines

Where to Get Field Operation Data From?

- **Pilot installation**
  - Ocean-going tanker vessel in regular operation
  - Equipped with
    - 5X72DF WinGD dual fuel engine featuring WiDE
    - Geislinger TV damper featuring GMS
- **Database generation**
  - Navigation, voyage, engine, and vibration data
    - Collected onboard with WiDE and GMS
    - Transmitted via secure channels
  - Post-hoc data synchronization (1 sample/min)
  - Additional data preprocessing for further analysis

→ Database of 253 informative features covering more than one year of vessel operation



© WinGD

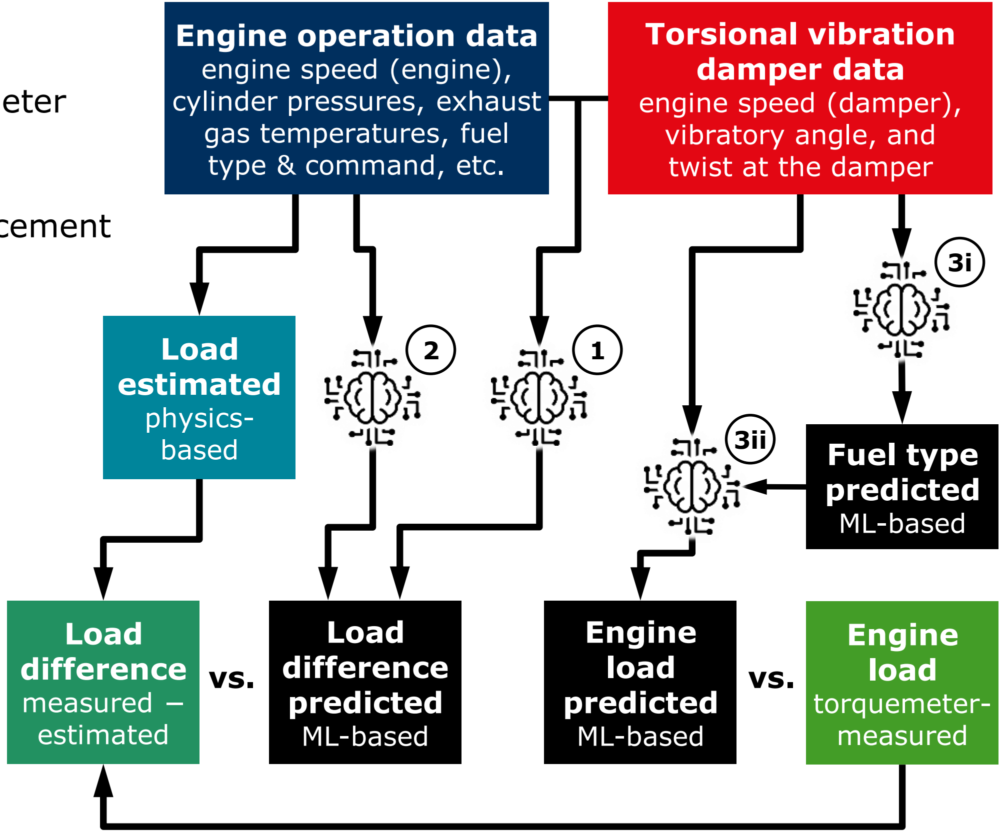
© Geislinger GmbH

Advanced CM of Large Engines

Use Case: Virtual Load Sensor

- **Motivation**
  - Engine load is key performance parameter
  - Currently measured with torquemeter
  - Virtual load sensor as backup or replacement

- **Modeling scenarios**
  1. Combined data sources
  2. Engine operation data only
  3. TV damper data only
     (incl. fuel type prediction)

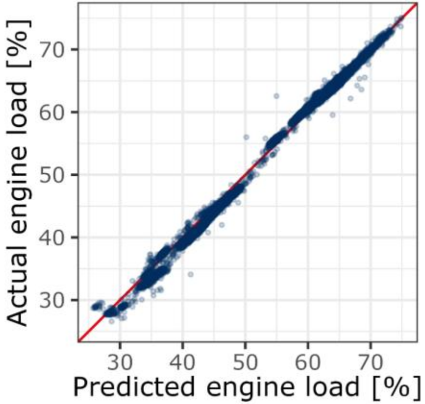


Virtual Load Sensor

Machine Learning Framework and Results

- **Model training and comparison**
    - Nested k-fold cross-validation (CV) framework employed
    - Two voyages as final test set (data not used for model training)
    - Various AI/ML methods compared under multiple feature scenarios
- **Results**
    - Best CV results with combined data scenario
      (Mean absolute percentage error, MAPE, of 0.59 %)
    - Error on unseen test data: MAPE of 1.14 %
    - TV damper only scenario
        - CV error: MAPE of 0.83 %
        - Test error: MAPE of 1.25 %
        - Fuel type classification: 0.99 Matthews correlation coef.

Test set predictions
Combined data scenario



→ Results demonstrate benefit of data sharing, as well as potential for self-contextualization

AI-Enhanced CM = Success?

Great Potential But Some Challenges Remain

- **Challenges of AI-enhanced CM for maritime applications**
  - Generalization to changing operating conditions and fleet-wide application
  - Field data acquisition cumbersome (often third-party ownership)
  - Scarcity of faults/failures during real-world operation
  - Trustworthiness, explainability and legal aspects
  - Cybersecurity and system resilience
  - Technical vs. commercial feasibility
  - Environmental impact of AI
  - …

Where lies the future of AI-enhanced CM?

Of course, tackle all these issues!

Edge-based solutions with tinyML

Edge-Based CM With TinyML

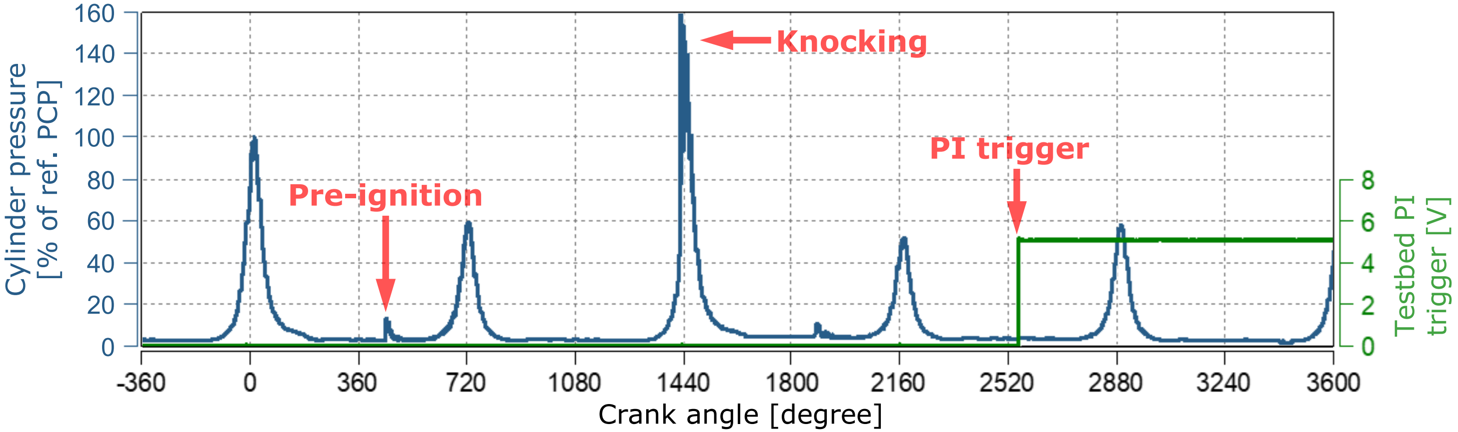
LEC's Motivation

- **TinyML in general**
    - ML subfield focused on deploying lightweight models on microcontrollers and other edge devices
    - Data analytics performed close to data source (reducing data volume and latency)
- **Advantages for large engine CM**
    - Bring existing cloud-based solutions back to the engine or component
    - Enable data-intensive condition detection methods
    - Allows for immediate sensor/measurement self-validation
- **Some use cases in engine development**
    - Sensor validation in telemetry-based condition detection systems
    - Condensation of high-frequency acoustic emission data
    - Real-time control reaction in case of combustion anomalies

Advanced CM of Large Engines

Use Case: Edge-based *Knock Block*

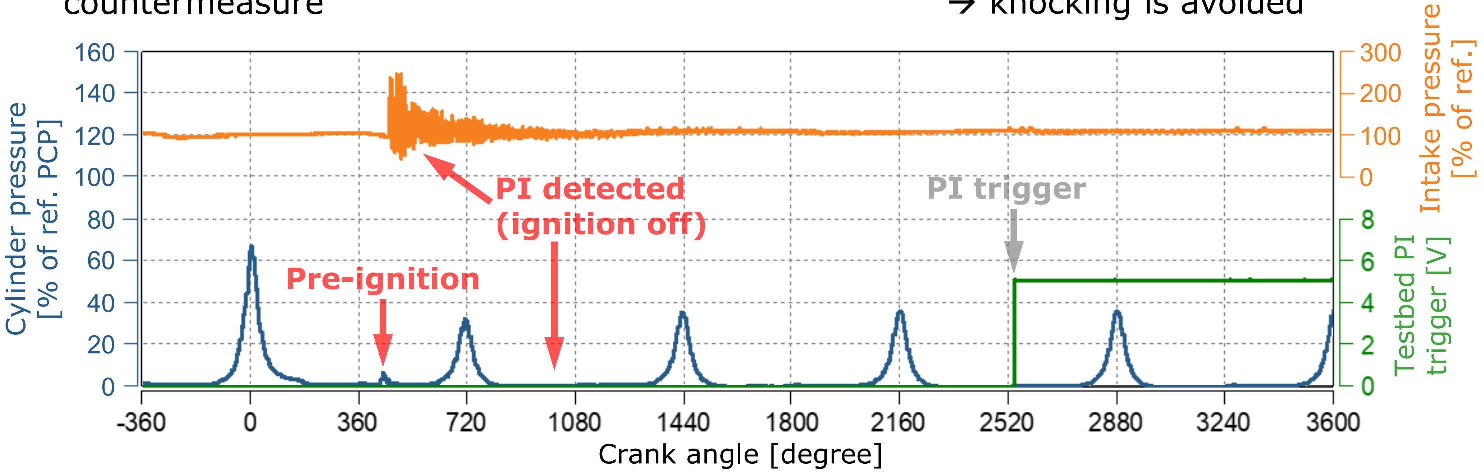
- **Motivation**
  - Pre-ignition (PI) events during high-load hydrogen operation often followed by knocking
  - However, PI detection from test bed software is too slow for triggering a countermeasure



Advanced CM of Large Engines

Use Case: Edge-based *Knock Block*

- **Motivation**
  - Pre-ignition (PI) events during high-load hydrogen operation often followed by knocking
  - However, PI detection from test bed software is too slow for triggering a countermeasure
- **Knock Block**
  - Edge computing is used to detect PI via intake manifold pressure (microcontroller-based, few € cost)
  - For immediately following cycle, injection is switched off → knocking is avoided



Advanced CM of Large Engines

A Journey Worth Taking?

- **Condition monitoring process** offers many opportunities for advancement

Condition detection	Condition comparison	Diagnosis

- Great potential of **AI-enhanced CM**, yet some challenges remain
- **Edge-based analytics** promising to
    - support in engine development,
    - reduce AI’s environmental impact in field applications,
    - and make CM more resilient and reliable overall

> **“It's worth remembering that it is often the small steps, not the giant leaps, that bring about the most lasting change.”** Queen Elizabeth II
> (the person, not the ship)

Thank you for your attention!

Evolutionary Green Energy
and Transport Systems
for a Sustainable Tomorrow

Contact:

Dipl.-Ing. Dr.techn.
Thomas Jauk
CEO
Email: thomas.jauk@lec.tugraz.at
Tel.: +43 316 873 30063

Univ.-Prof. Dr.-Ing.
Nicole Wermuth
CSO
Email: nicole.wermuth@lec.tugraz.at
Tel.: +43 316 873 30087

LEC GmbH – Large Engines Competence Center
Inffeldgasse 19 | 8010 Graz, Austria
www.lec.at

LEC GETS is a COMET Center within the "COMET - Competence Centers for Excellent Technologies Programme" and funded by the Austrian Federal Ministry for Innovation, Mobility and Infrastructure (BMIMI), the Austrian Federal Ministry for Economy, Energy and Tourism (BMWET) and the co-financing federal provinces of Styria, Tyrol and Salzburg. The COMET Programme is managed by the Austrian Research Promotion Agency (FFG) •