



JUNE 10, 2021 | GEOFF DUFF

ADVANCED WASTEGATE TURBOCHARGERS

Commercial Vehicle

Garrett
ADVANCING MOTION

Garrett mission



Garrett is a cutting-edge technology provider that enables vehicles to become safer, more connected, efficient and environmentally friendly

We lead the development of innovative and differentiated solutions which empower the transportation industry to redefine and further advance motion

AGENDA

1. Garrett Overview
2. Commercial Vehicle Trends
3. Engine Strategies & Implications for Air System Requirements
4. Next Generation of Wastegate Turbo Technologies
5. Q&A

Garrett at a glance

\$3B

Revenue in 2020

~7,500

Employees

~1,250

Engineers

40

Vehicle manufacturers served globally

5

R&D centers

11

“Close-to-customer”
engineering centers

5

Software development
centers

1,600+

Patents issued or pending

13

State-of-the-art
manufacturing facilities

100+

New applications annually

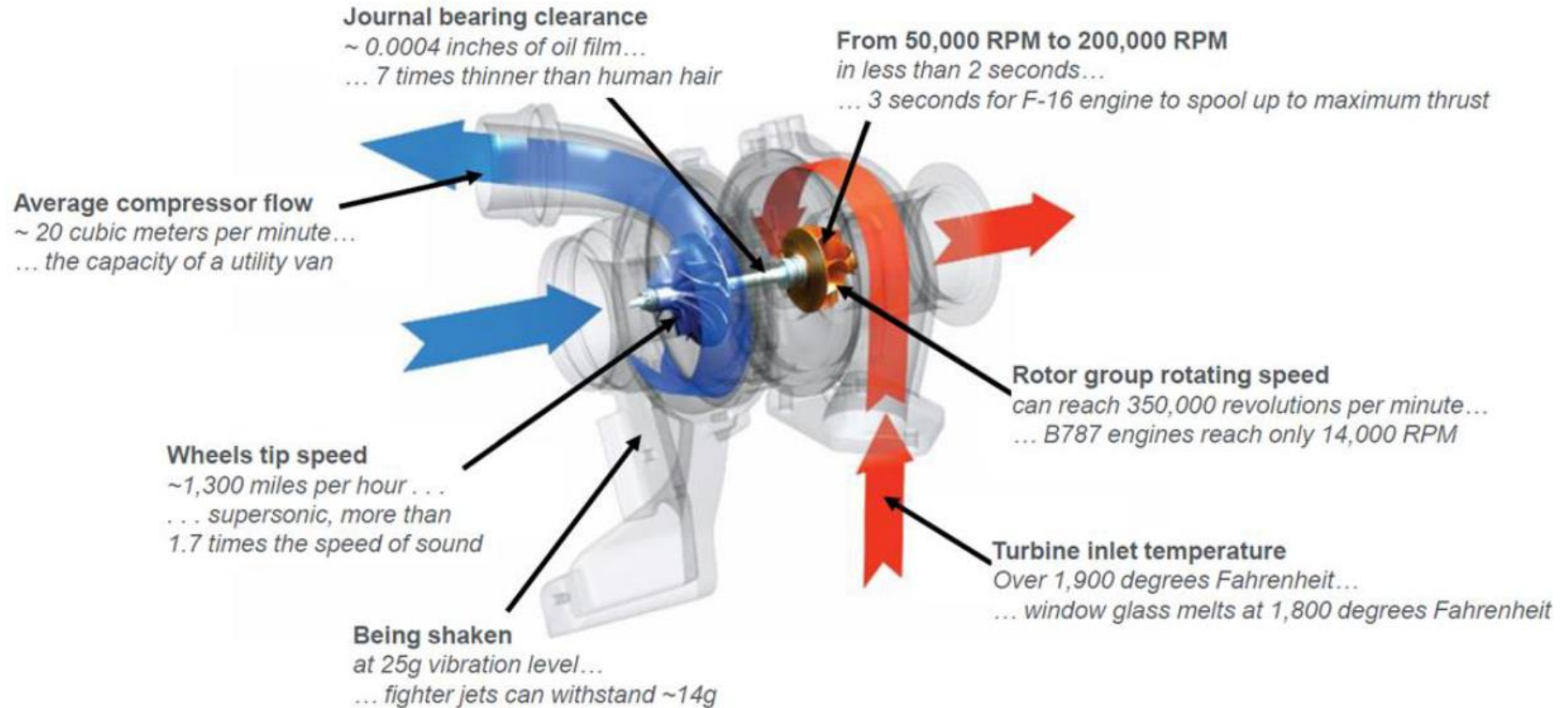
50,000+

Turbos / day

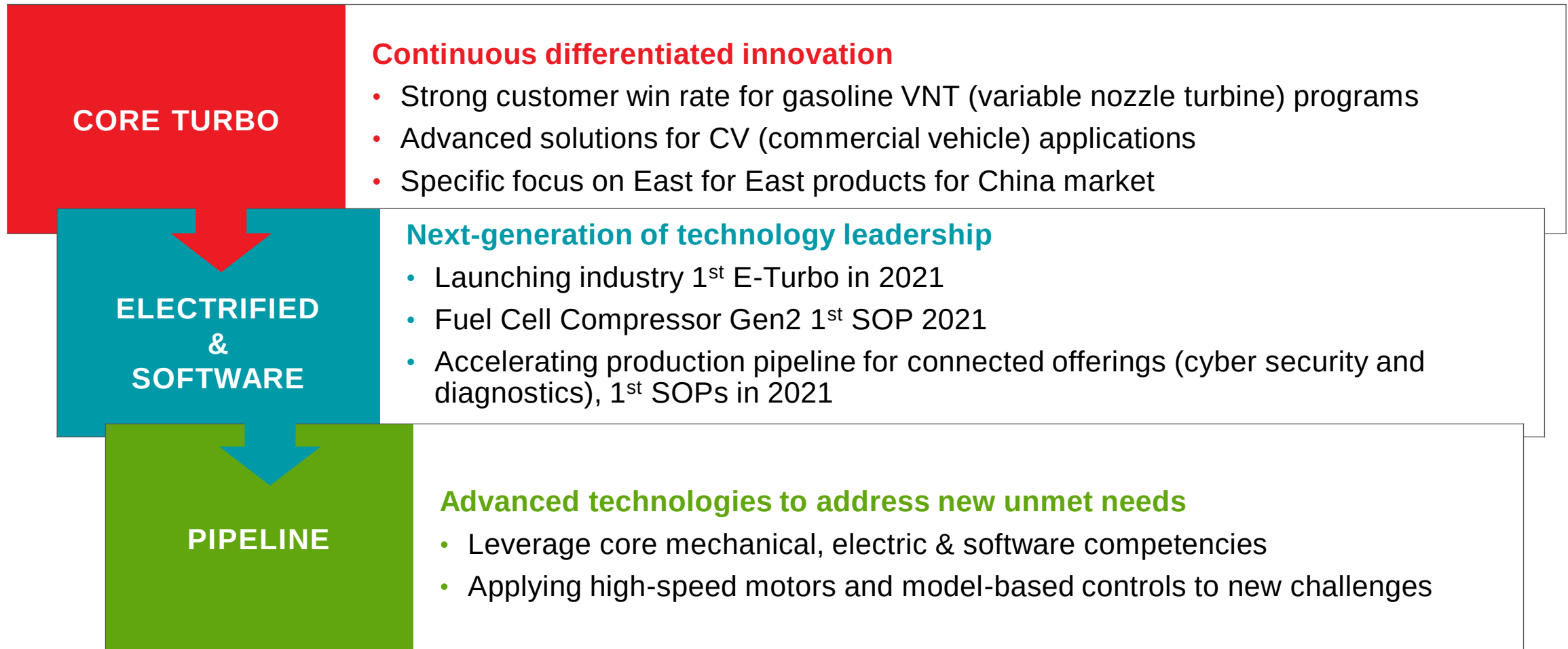
110M+

Garrett turbos in use globally

Turbocharger technology demands



Garrett technology & growth strategy



CV trends and Garrett offerings



General OEM trend

CORE



Diesel & CNG (Compressed Natural Gas)



New Aftertreatment System, EGR compatibility, Thermal Management

Electrification



Full Battery Electric Hybridization (48/400/800V) Regeneration benefit w/ e-turbo



FCC (fuel cell compressor) Power modularity H2 – ICE transition for 0-carbon

Connected Vehicle



Greater system complexity Advanced Control IVHM (integrated veh health monitoring) in new service model Cyber security scrutiny

Garrett Offering

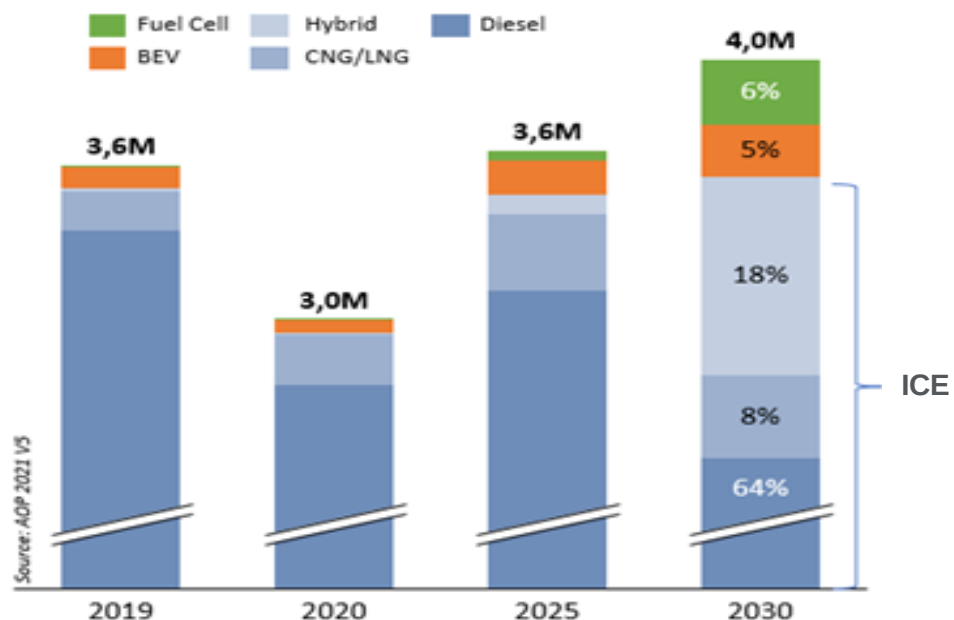
WASTEGATE	TWO STAGE	DOUBLE AXLE VNT

E-COMPRESSOR	E-TURBO	FC COMPRESSOR	H ₂ - ICE

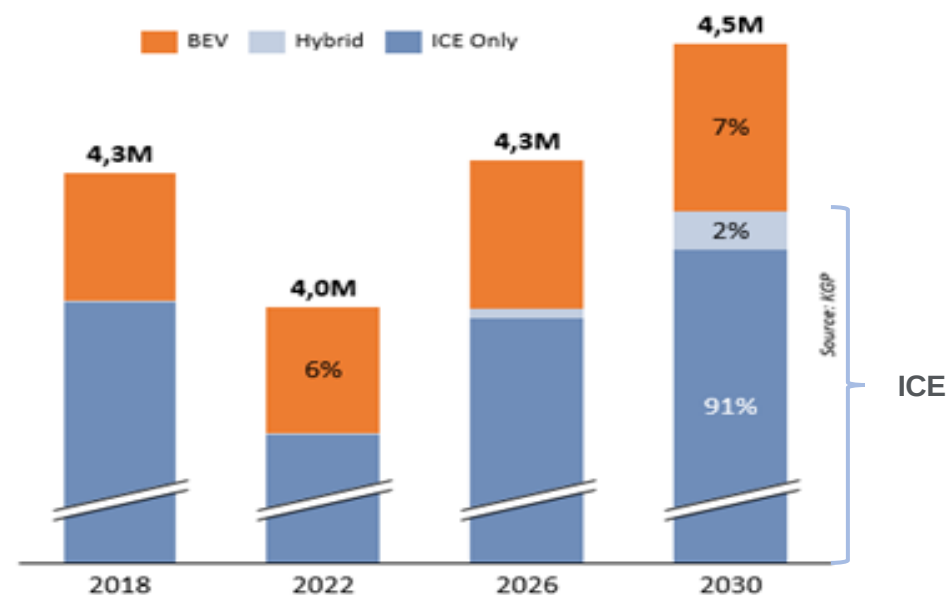
ADV. CONTROL	IVHM	CYBERSECURITY

Challenges and technology trends in CV

On-Highway



Off-highway



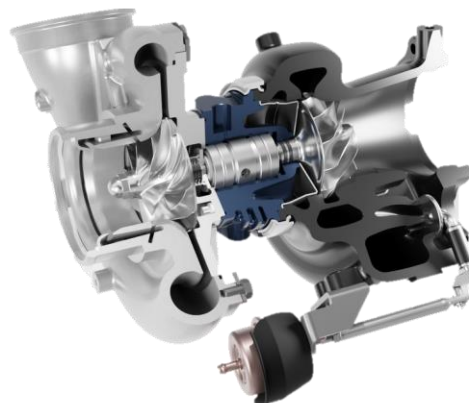
Need for advances in ICE technology for CV exists beyond 2030

Conventional turbocharger systems

FIXED GEOMETRY



WASTEGATE



VNT (VARIABLE NOZZLE TURBINE)



Control / Regulation

- No internal regulation

- Turbine Bypass (poppet style)
- Electric or Pneumatic Actuation

- Turbine Nozzle (moving vane)
- Electric or Pneumatic Actuation

Benefit

- Traditional turbo design
- Lowest complexity

- **Full but course flow regulation**
- Improved altitude performance
- **Thermal management capability**

- **Full modulation and fine flow control**
- More boost at lower engine speeds
- **Ability to drive high EGR rates**

Application

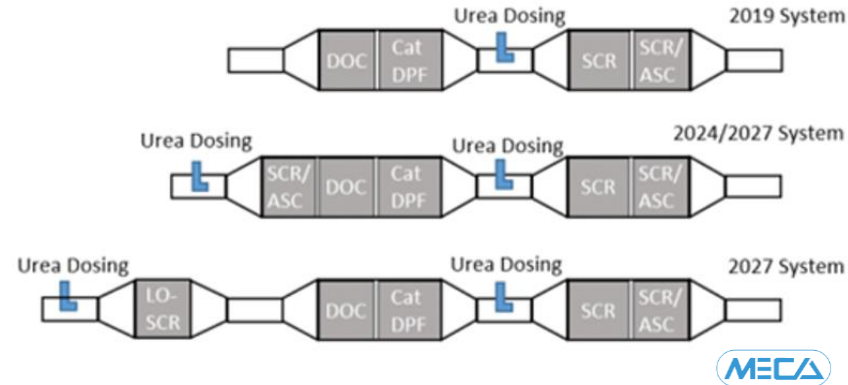
- Large Off-hwy (ex. Stationary, 2-stage systems)

- On & Off Highway CV / LV
- SCR only and some EGR engines

- On & Off Highway CV / LV
- High EGR rate ICE

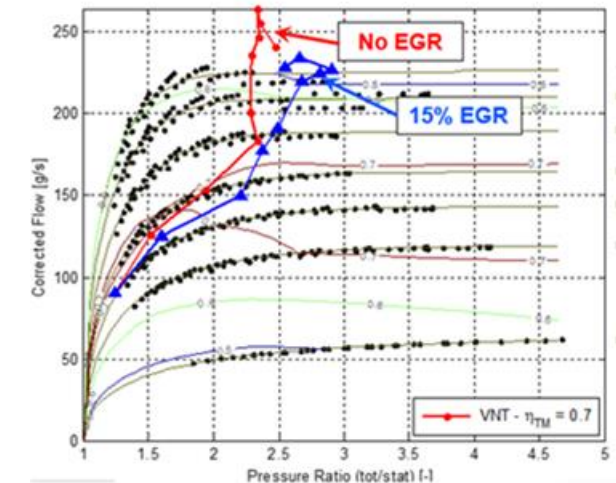
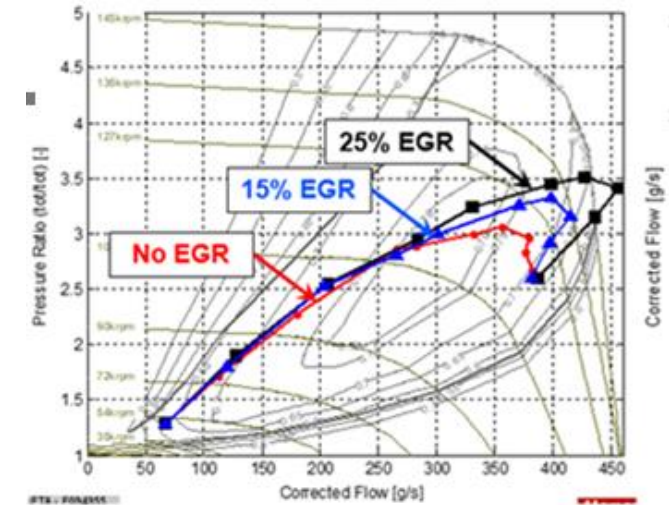
EGR vs SCR strategy – criteria pollutant strategy

- Advances in aftertreatment systems capable of achieving significant reductions in criteria pollutant
- Varying levels of SCR and EGR expected to exist beyond 2027



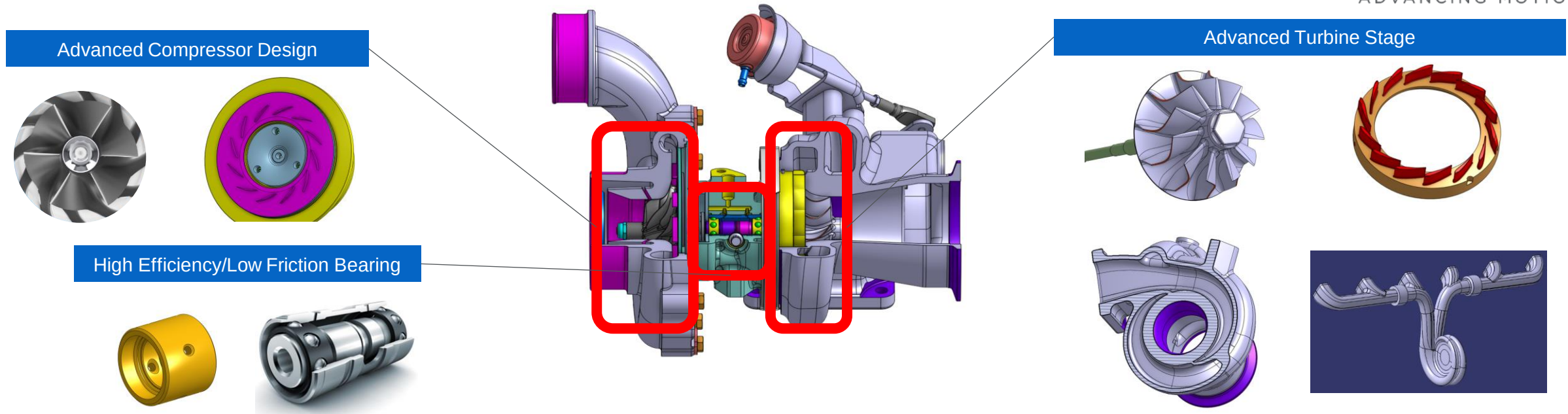
OPERATING CHARACTERISTICS & TURBO REQUIREMENTS

Emissions Strategy	Compressor	Turbine
SCR (selective catalytic reduction)	- Lower pressure ratio ~3.0 - Narrower flow range	- Higher flow range - Lower expansion ratio (optimized efficiency w/ out need for negative engine delta pressure)
EGR (exhaust gas recirculation)	- Higher pressure ratio ~3.5+ - Wider flow range	- Lower flow (recirculation) - High expansion ratio >2.8 - Requires negative engine delta pressure



Emissions strategies and engine architecture vary requiring flexible turbocharger solutions

Modern wastegate turbocharger design



TECHNOLOGY CAPABILITY

OBJECTIVE: DRIVE OVERALL TURBO EFFICIENCY >65% (Overall Turbo eta = Compressor ETAc X Turbine ETAtm)

FEATURE	TURBO BENEFIT	ENGINE BENEFIT
Turbine & Vanes	ETAtm - Low Flow Efficiency Peak Efficiency @ FE Pts	BSFC / CO ₂ Improvement Pulse Utilization and/or Separation
Compressor	ETAc - Peak Efficiency Optimization for FE (fuel economy) Pts	
Bearing & Seals	ETAmeh - New high efficiency Journal & Ball Bearing Oil deflector	Transient load step + low end BSFC Robust sealing

New features capable of maximizing wastegate turbo efficiency for CO₂ & emissions reduction

Compressor and turbine performance

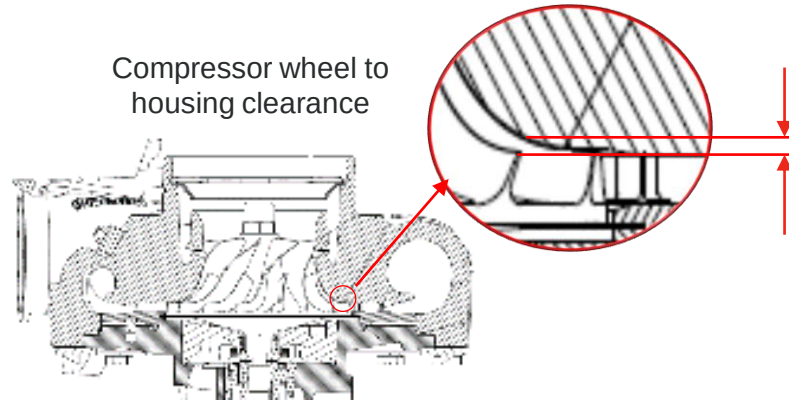
Vane Diffuser



Compressor wheel w/
vane diffuser

- Improved low flow efficiency
- More narrow operating range but higher overall efficiency
- Optimization of stage by vane angle and height

Compressor Clearance Reduction



- Abradable coatings / Smart Assembly
- Offers efficiency improvement across full map

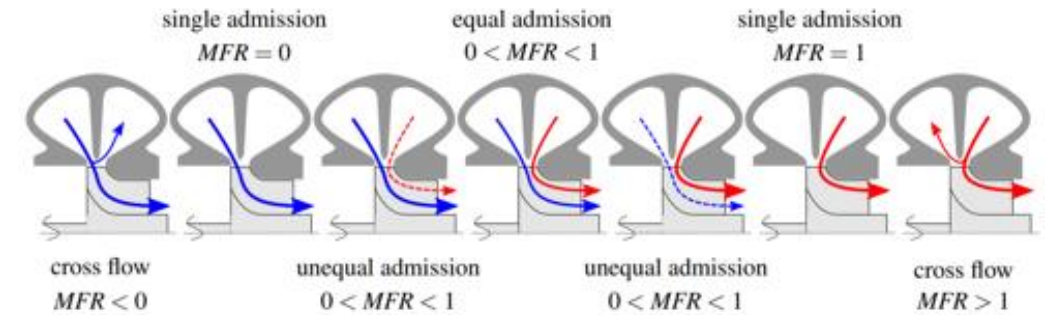
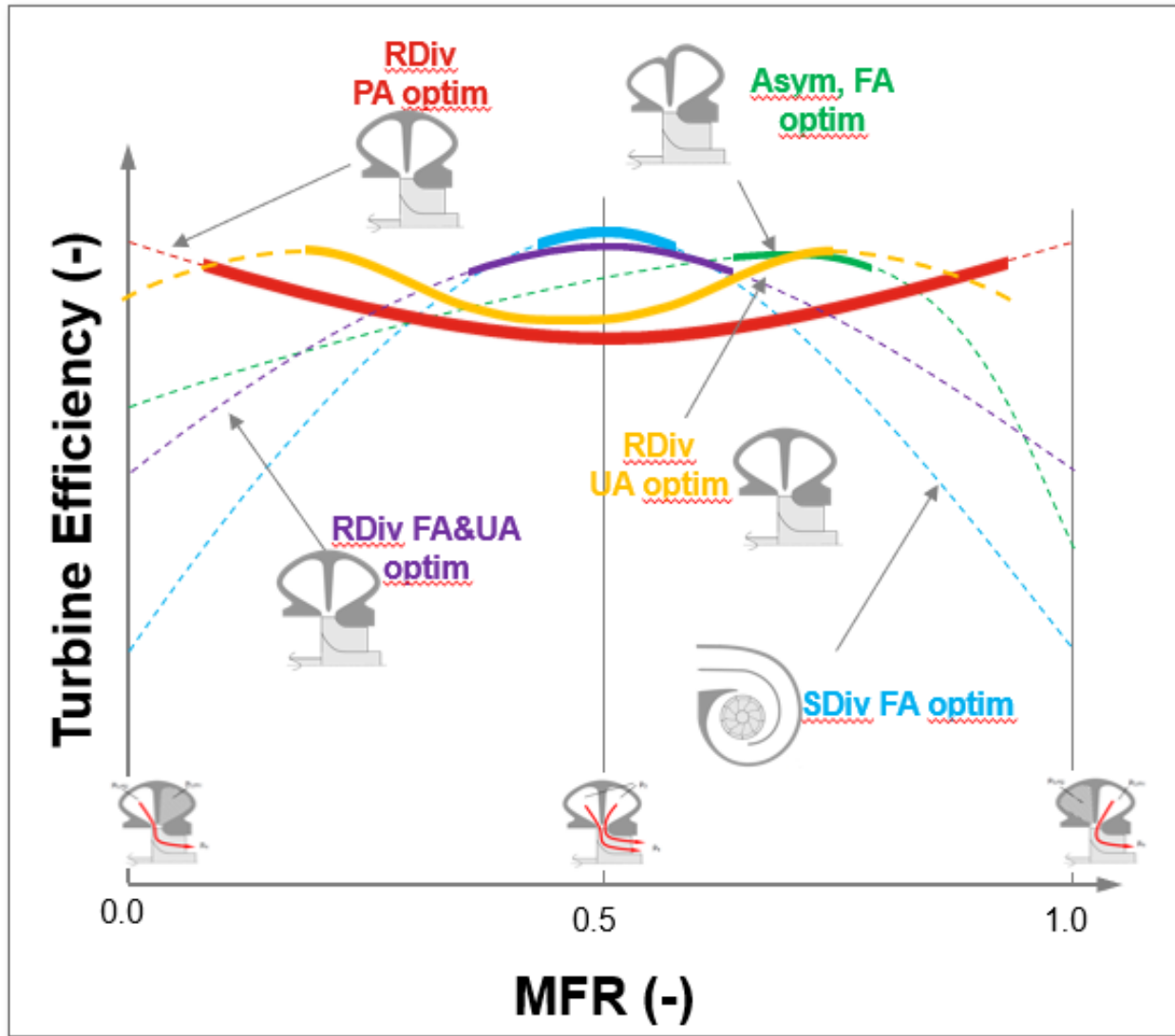
Fixed Vane Nozzle



Turbine Side Nozzle w/
Fixed Vanes

- Reduced velocity in cast volute → high velocity in nozzle
- uniform flow entering wheel vs radial passage
- Benefit most pronounced at high pressure ratio

Turbine performance – divided housings



*Luckmann, D et.al. "Investigation of cross flow in double entry turbocharger turbines" Proceedings of ASME Turbo Expo 2016, GT2016-57190

- Divided housings offer optimized turbine performance where it is needed most
- Maintains flow separation to turbine wheel → cylinder blowdown separation
- SD improves efficiency at full admission when MFR (mass flow ratio) = 0.5
- A-symmetric divided → Improved EGR drive vs turbine efficiency trade-off

Up to 0.5-1% fuel consumption benefit from divided housings

Additional features to improve wastegate turbos

ADDITIONAL WASTEGATE TURBO MODULES

Abrasive Flow Machining



***What
It Is***

**Improved Housing
Surface Finish**

***What
It Does***

**Reduces gas
passage friction
loss for efficiency**

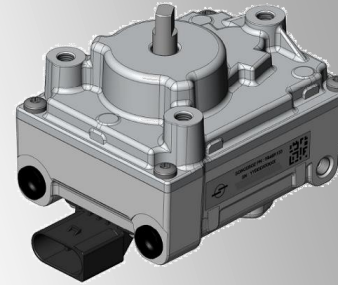
Ball Bearing



**Ball bearing
cartridge - available
on most product
sizes**

**Reduces bearing
loss resulting in up
to +1 % Fuel**

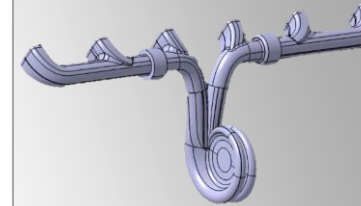
Electric Actuation



**Wide range of e-
actuator types and
sizes for on/off
highway applications**

**Thermal Mgt |
Higher Degree of
Bypass Control**

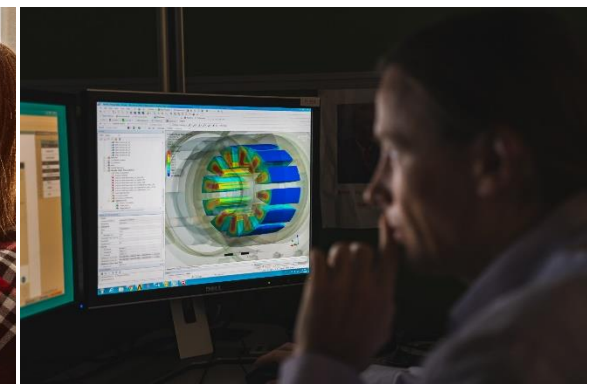
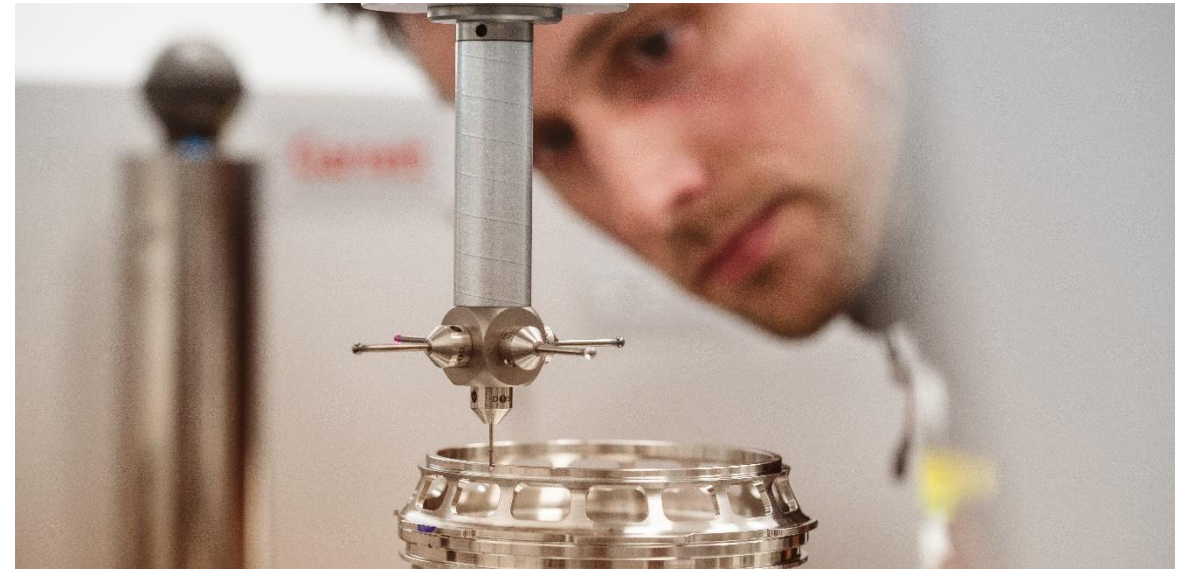
Integrated Turbine Hsg & Manifold



**Integrated manifold
and turbine hsg for
optimal
flow/performance**

**Improved stage
efficiency and fuel
economy benefit**

Talent at Garrett: working today on the vehicles of tomorrow



Photos on this slide were taken before the pandemic



www.garrettmotion.com



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