Flexible Machinery Solutions in Geothermal

GEMS Workshop, Nov 19/20, 2024

Atlas Copco Gas and Process

This is Atlas Copco

- Customers in **180** countries
- **53 000** employees in **71** countries
- Established in **1873** Stockholm, Sweden
- Turnover of nearly **173** BSEK / **15** BEUR*
- Operating margin of **21.5%**

*Based on the average exchange rate in 2023.

Atlas Copco

A decentralized Group

BOARD OF DIRECTORS

PRESIDENT AND CEO

GROUP MANAGEMENT

COMPRESSOR TECHNIQUE

- Compressor Technique Service
- Industrial Air
- Oil-free Air
- Professional Air
- **Gas and Process**
- Medical Gas Solutions
- Airtec

VACUUM TECHNIQUE

- Vacuum Technique Service
- Semiconductor Service
- Semiconductor
- Semiconductor Chamber Solutions
- Scientific Vacuum
- Industrial Vacuum

INDUSTRIAL TECHNIQUE

- Industrial Technique Service
- MVI Tools and Assembly Systems
- General Industry Tools and Assembly Systems
- Chicago Pneumatic Tools
- Industrial Assembly Solutions
- Machine Vision Solutions

POWER TECHNIQUE

- Power Technique Service
- Specialty Rental
- Portable Air
- Power and Flow

Markets Served by Gas and Process Division

Energy Transition Applications

Hydrocarbons

- Midstream
- LNG
- Olefins / Polyolefins
- Chemicals / Petrochemicals
- Refinery

Air Separation

Power Generation

- Fuel Gas Boosting

New Energy

- Thermal Energy Storage
- sCO_2 / Renewables
- Industrial Heat Pumps

Emerging Markets

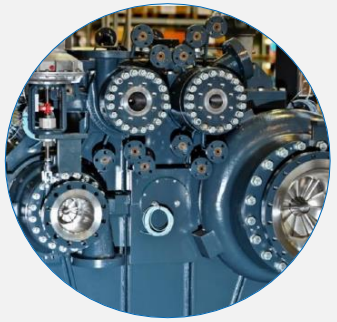
- CCUS
- Hydrogen

Global Climate and Human Health Protection

Turbomachinery is required to support **new, emerging** and **sustainable energy sources**

Increased amount of **H_2, CO_2, electrification and energy conversion related projects**

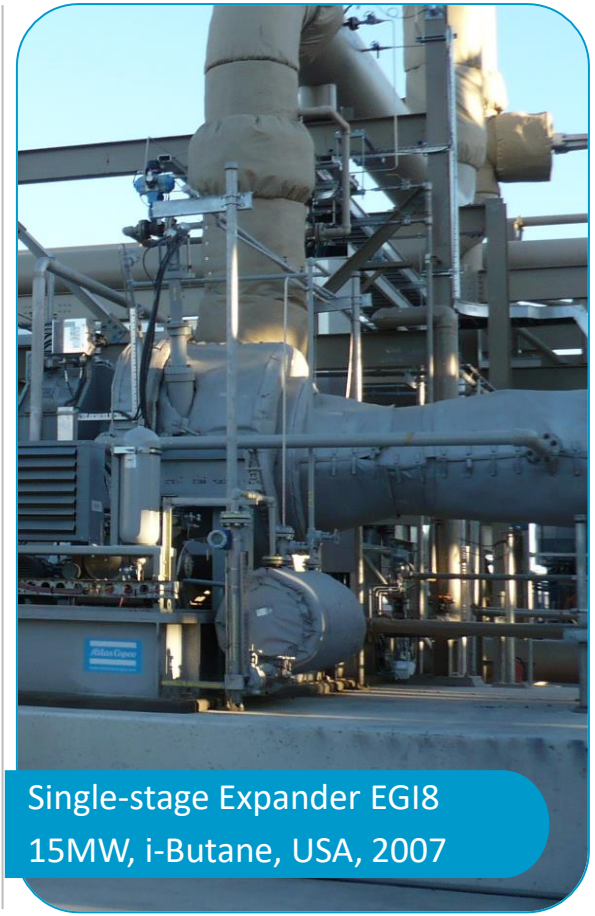
Expanders / Compressors in H_2 Liquefaction and BOG	Expanders / Compressors in CCUS and sCO2	Steam Compressors / MVR & Heat Pumps	Expanders / Compressors in **ORC** / WH2P / LDES



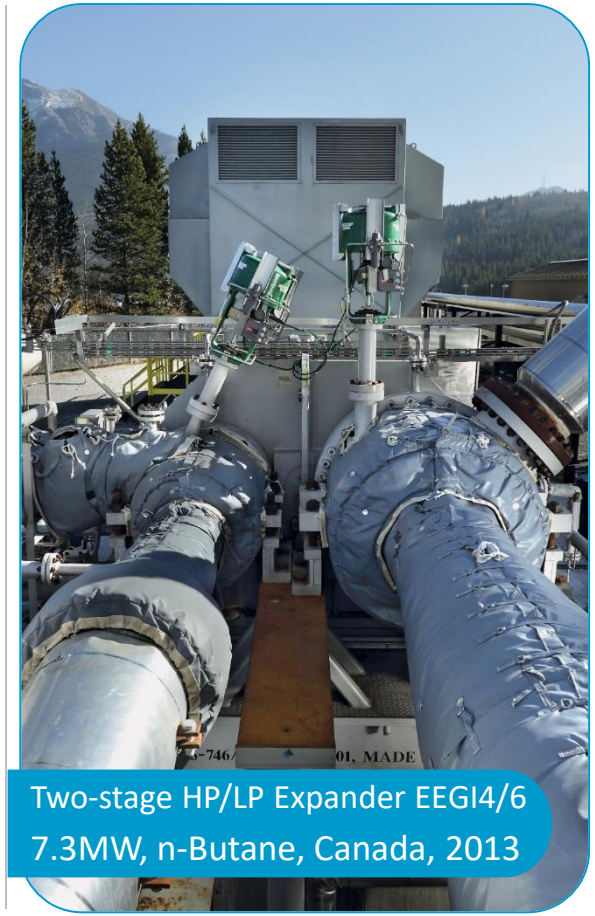
Atlas Copco Expanders in ORC

Decades of Experience in Binary ORC Plants

Single-stage Expander EG10
10MW, i-Butane, USA, 1982



Single-stage Expander EGI8
15MW, i-Butane, USA, 2007

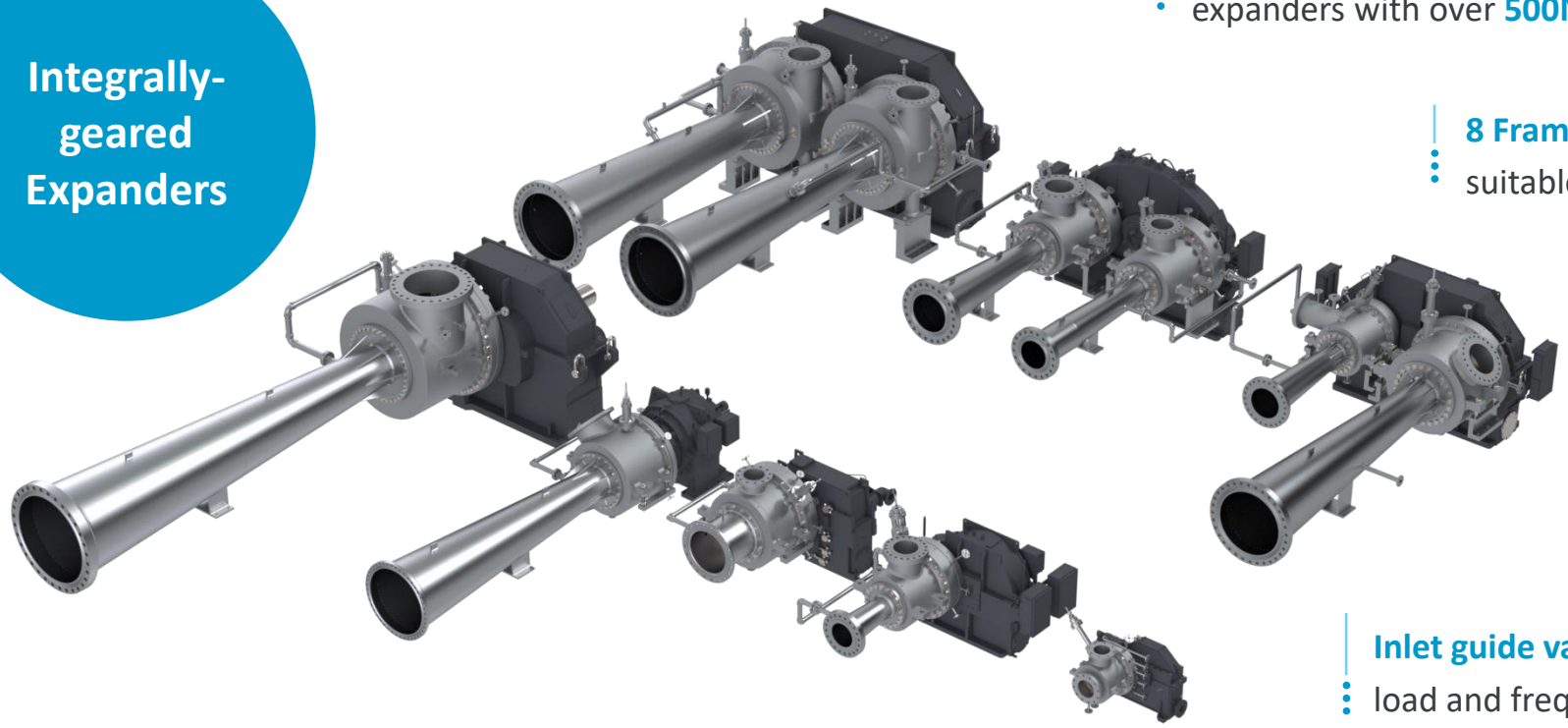


Two-stage HP/LP Expander EEGI4/6
7.3MW, n-Butane, Canada, 2013

Dual-stage Expander EEGI8
27MW, n-Butane, Turkey, 2018

Atlas Copco Expanders in ORC

Integrally-geared Expanders



Atlas Copco is an EPC-independent major brand for ORC expanders with over **500MW** in more than **40** installations

8 Frame Sizes cover power range from **5 to 30+MW,** suitable for small demo plants to full commercial scale

Integrally geared design allows compact and flexible multistage units (parallel, HP/LP etc)

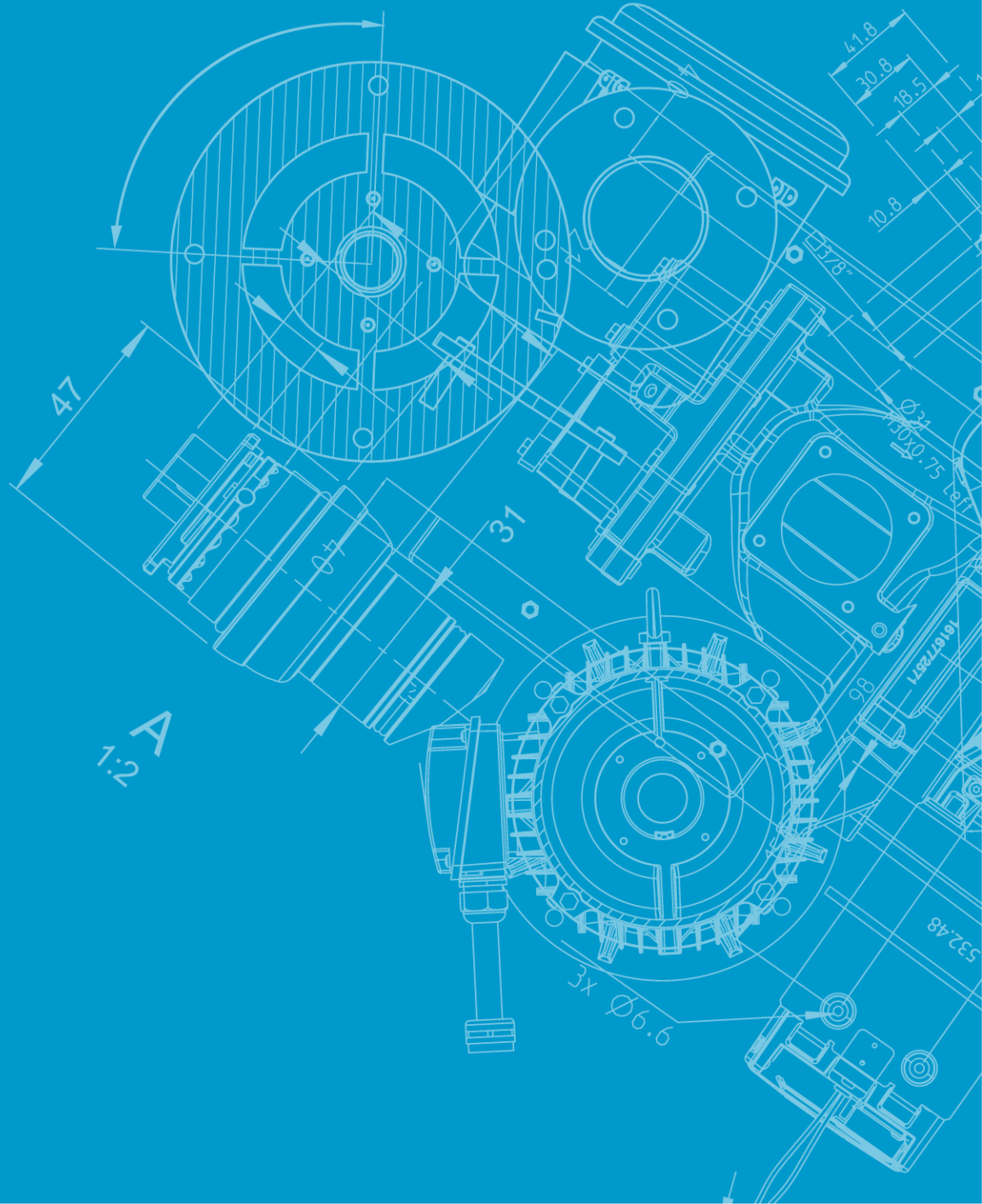
Zero leakage configurations possible, sealing options include oil, dry gas, and labyrinth

Inlet guide vane technology allows precise and fast load and frequency control including “island mode”

Mature technology with documented **availability >98% p.a.,** due to continuous design improvement and implementation of “lessons learned”

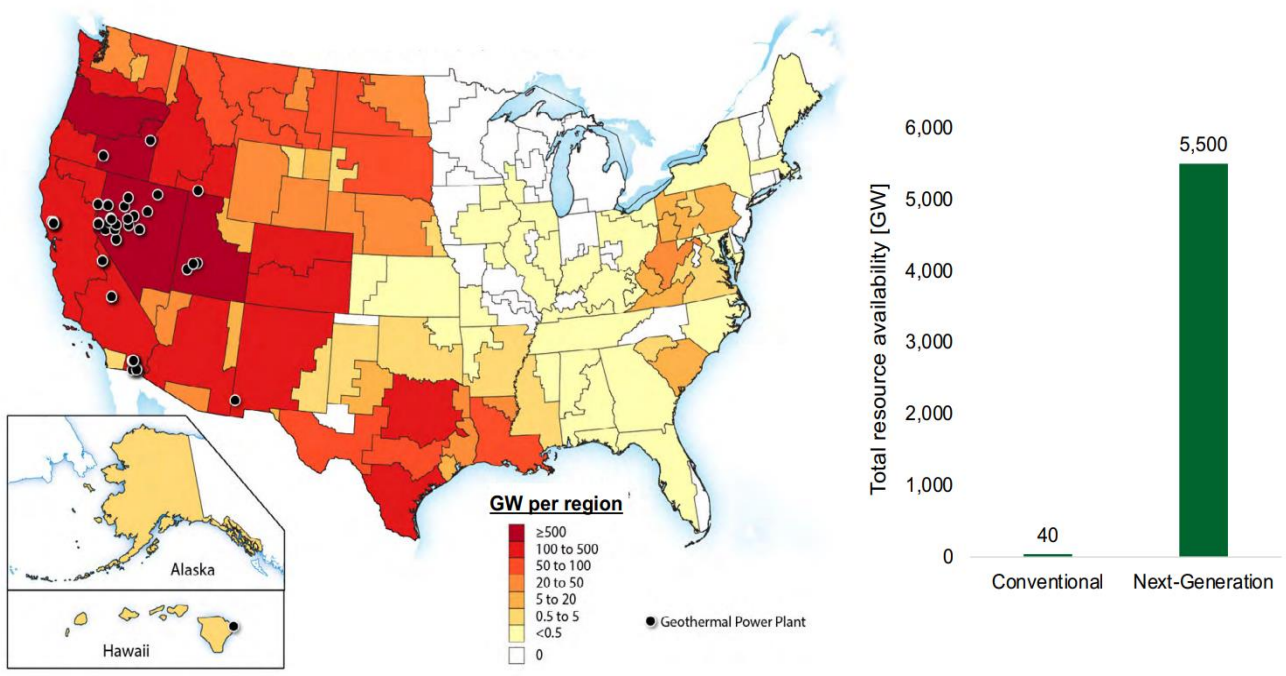
Advancing Geothermal Power

The Role of Flexible Machinery in Next-Generation Geothermal Integration



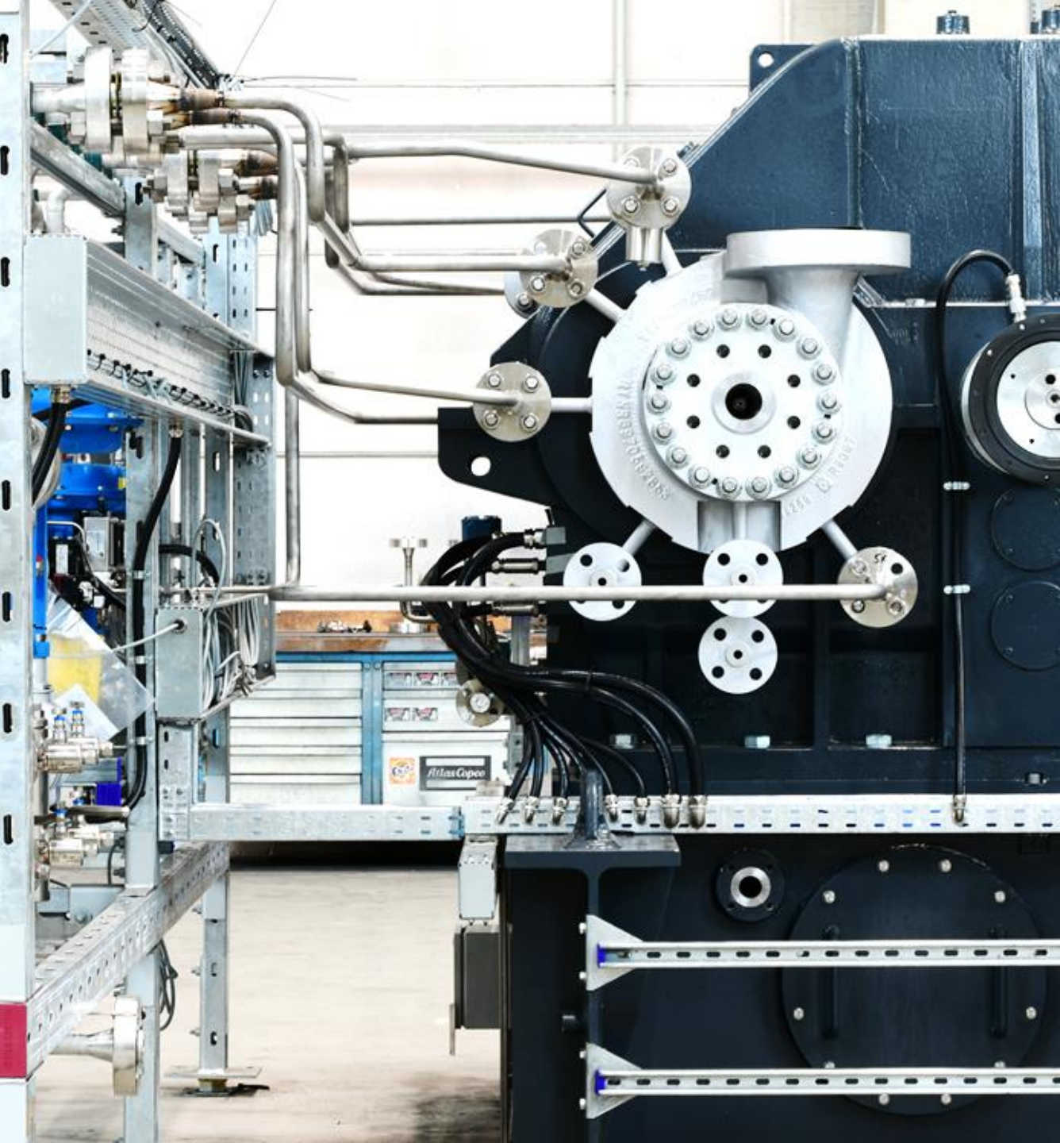
Advancing Geothermal Power

The Role of Flexible Machinery in Next-Gen Geothermal Integration



Source: Pathways to Commercial Liftoff: Next-Generation Geothermal Power, DOE, March 2024

- **Next-generation geothermal** technologies unlock resources in common environments, increasing accessibility and commercial potential
- **Flexibility in surface machinery** is essential for integrating next-generation geothermal power into the **modern grid**
- Transitioning from conventional to next-generation geothermal requires flexible solutions in **design**, **supply**, and **operation**



Advancing Geothermal Power

Flexibility in Design

Conventional Approach

- Well Established ORC Designs and Working Fluids
- Modular Steam and Binary Arrangements

Next-Generation Needs

- Advanced Designs / Working Fluids for higher temperature and performance
- A balance between modularity and scale

A Way Forward

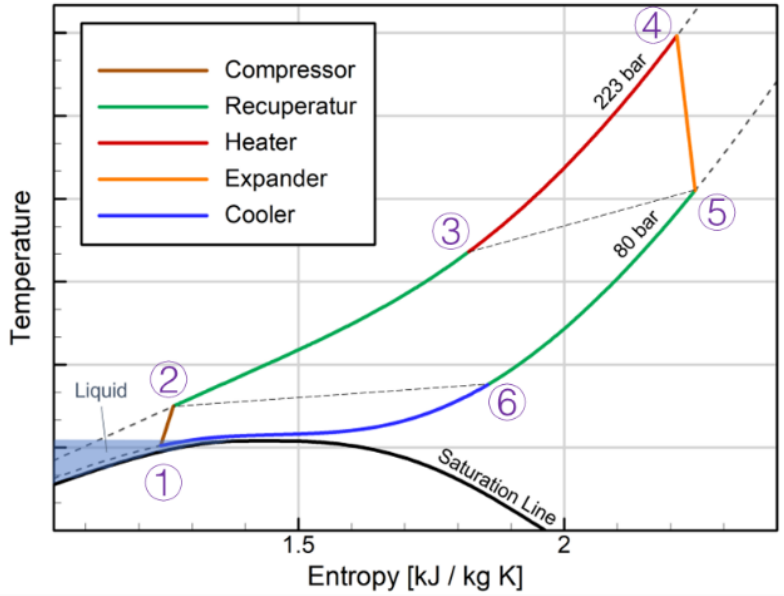
- Continuous improvement of surface equipment through proven ETO to CTO process
- More power-dense direct or indirect cycles

Compander for sCO2 Power Plant

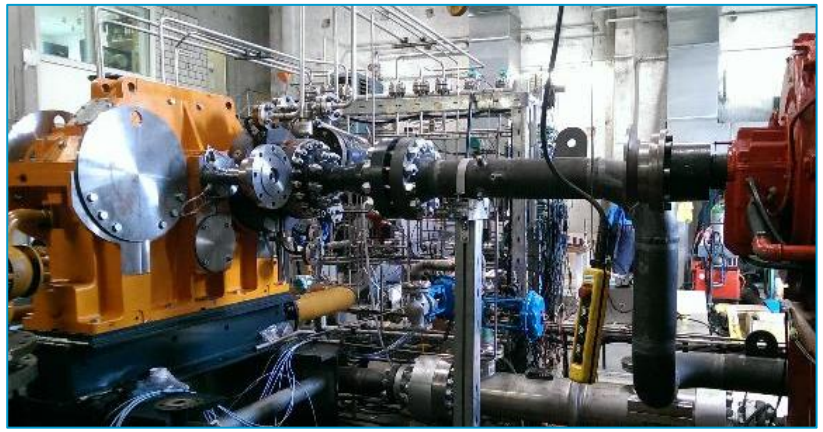
Flexible Design Example

- Request received for **custom compander design** for sCO2 power cycle
- Unique compressor design included **liquid suction** and operation near critical point
- Design was tested on **in house, high pressure sCO2 loop** in 2021
- Approximately **10-times higher power density** compared to typical ORC expander
- Design can be **freely modified** for severe fluid / corrosion requirements of direct cycles

Expander / Gearbox / Compressor



	Compressor	Expander
Shaft Sealing	Dry Gas Seal	
Speed	38 000 RPM	
Mass Flow	174 600 kg/h / 385 000 lb/hr	
Impeller Dia	104 mm / 4.1”	150 mm / 6.0”
Inlet Pressure	80 bara	223 bara
Inlet Temp	28°C / 82°F	275°C / 530°F
Power	2 MW net	



Advancing Geothermal Power

Flexibility in Supply

Conventional Approach

- Available geothermal resources restricted to select locations
- Surface equipment deployment benefits from a vertically integrated structure

Next-Generation Needs

- Expanded geothermal accessibility across diverse regions
- Decentralized supply chains with options for local manufacturing

A Way Forward

- Diversity in equipment suppliers with global reach

Flexible Supply Example

Atlas Copco Gas and Process Division Global Structure

Sales, Application and Production Center USA

Atlas Copco Comptec LLC

Acquired in 1980

Sales, Application and Production Center USA

Atlas Copco Mafi-Trench LLC

Acquired in 2007

Sales, Application and Production Center Europe

Atlas Copco Energas GmbH

Acquired in 1984

Sales, Application and Production Center China

Atlas Copco (Shanghai) Process Equipment Co., Ltd.

Established in 2010

Sales, Application and Production Center Korea

Atlas Copco Korea Gas and Process

Established in 2021

Sales, Application and Production Center India

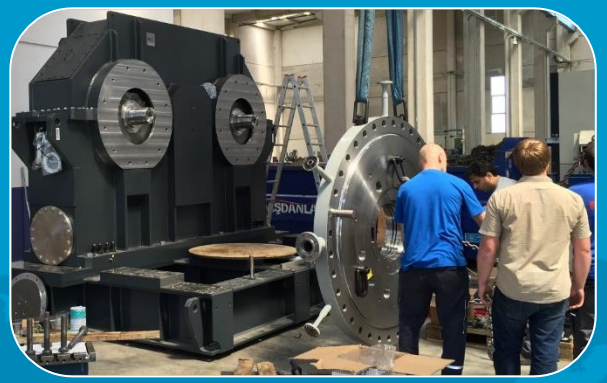
Atlas Copco (India) Ltd. Gas and Process Applications

Established in 1997

Flexible Supply Example

Atlas Copco Gas and Process Division Global Structure

Local Manufacturing in Turkey



US Turbomachinery Factory

German Turbomachinery Factory

Advancing Geothermal Power

Flexibility in Operation

Conventional Approach

- Baseload power with high utilization
- Operation optimized for single point efficiency

Next-Generation

- Dispatchable power that compliments other renewables
- Operation optimized for broader conditions to support grid balancing and stability

A Way Forward

- Dynamic processes and equipment responsive to daily/yearly weather patterns, grid demand, etc.

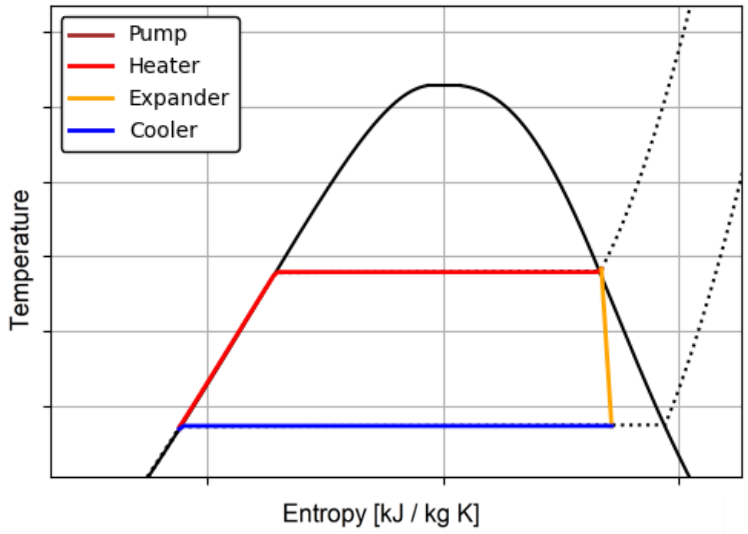
Image courtesy of RayGen

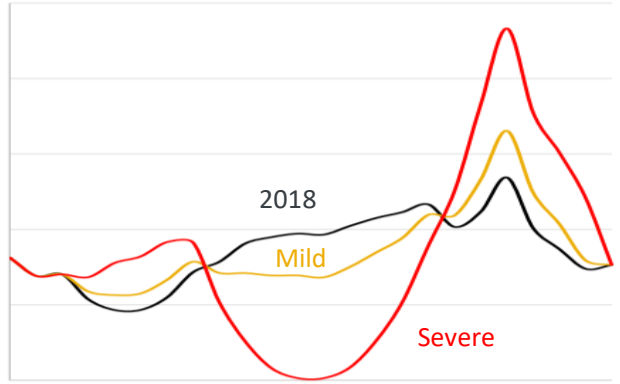
Atlas Copco

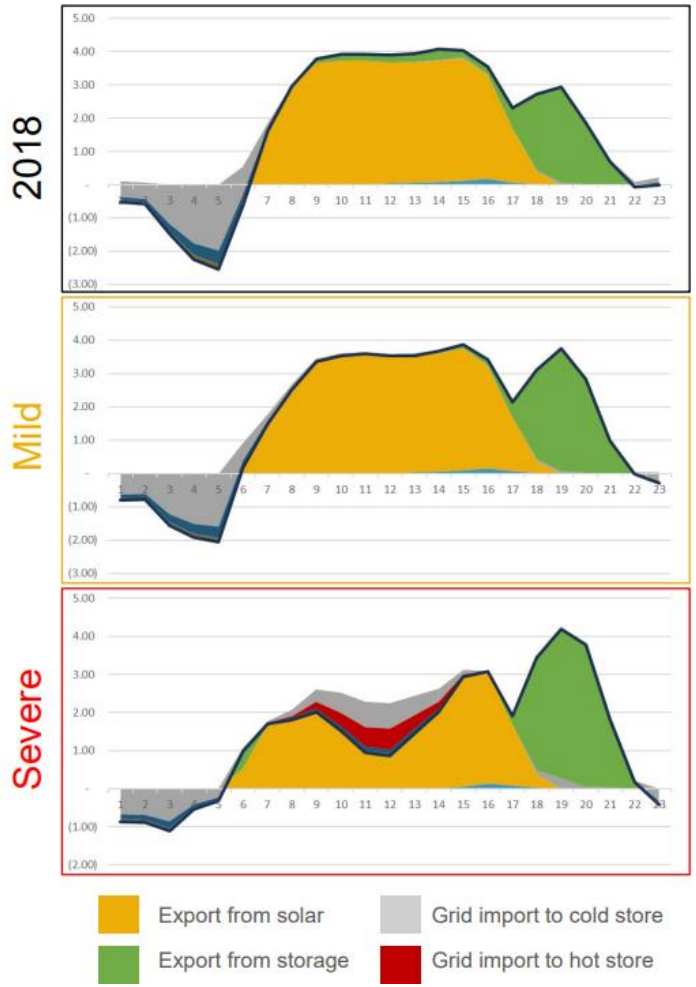
Expander in Thermal Energy Storage ORC

Flexible Operation Example

- Project partner sought to de-risk pilot thermal energy storage project by using proven tech from binary ORCs
- Design utilized low enthalpy ammonia ORC with **two-phase expander discharge**
- Daily start-stop with efficient performance over wide range of flows and enthalpy required **robust variable inlet guide vane assembly**
- Machine was **successfully commissioned and performance validated** in 2023, paving way for commercial scale



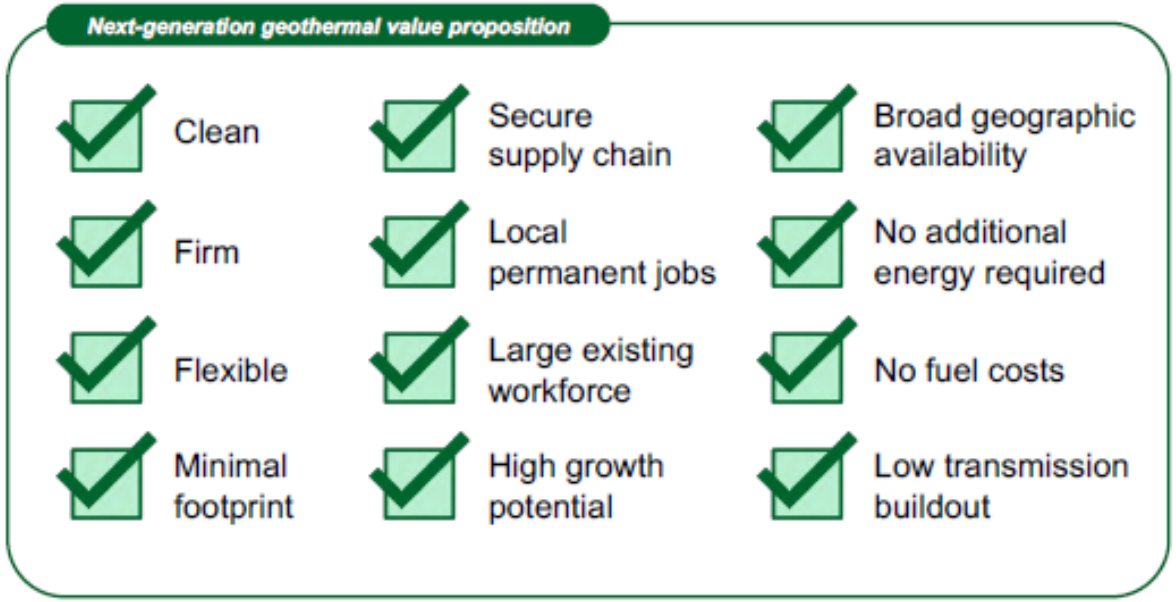




Source: RayGen Commercial Assessment Report, ARENA, May 2021

Conclusions

- **Flexibility in surface machinery** is essential for integrating next-generation geothermal power into the **modern grid**
- Established machinery suppliers offer flexibility in **design**, **supply**, and **operation** for next-generation geothermal deployment
- **Partnership** between machinery suppliers and plant builders offer **a low-risk path forward** for next-generation geothermal scale out



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