ENGINE
ENhanced Geothermal Innovative Network for Europe

m+w zander

The New Generation Kalina Cycle

Contribution to the conference
"Electricity Generation from Enhanced Geothermal Systems"

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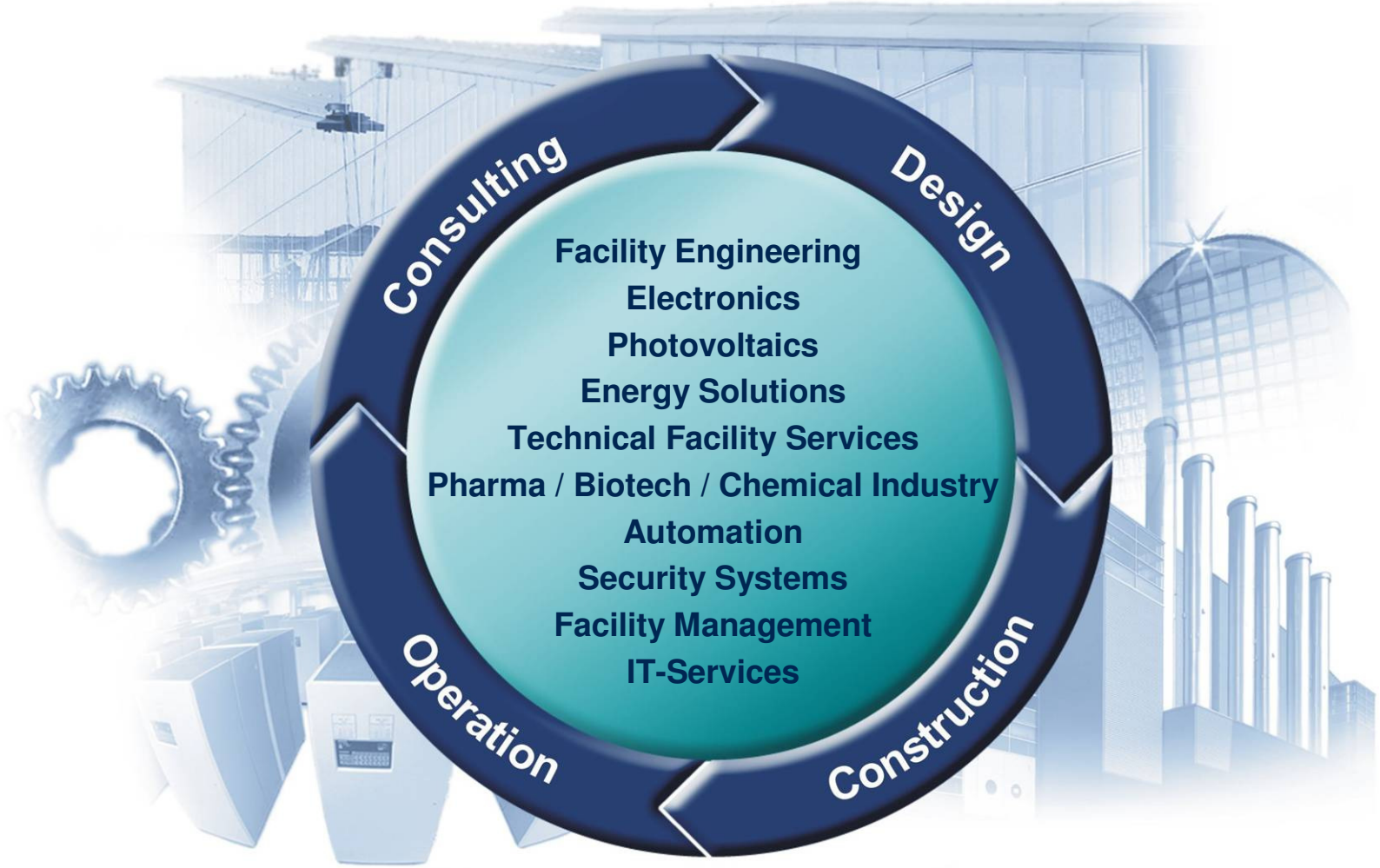
M+W Zander, Strasbourg, France September 14 2006

M+W Zander Markts and Services



Scope of Services

Consulting

Consulting Services, Evaluation, Programming

- Site Selection Services
- Feasibility Studies
- Architectural / Engineering Programming
- Economic Analysis
- Financial Engineering
- Process Development and Simulation
- Design Concepts

Design

Planning and Design

- Facility Planning
- Preliminary Design
- Value Engineering
- Conceptual, Basic, Detail and Final Design
- Facility Systems Integration
- Permits and Environmental Compliance
- Cost Optimization

Construction

Construction Management and Build

- Project Management
- Time Scheduling
- Cost Control
- General Contracting
- Tendering
- Manufacturing
- Procurement
- Construction
- Commissioning

- Single Source Responsibility
- Fast Track Execution

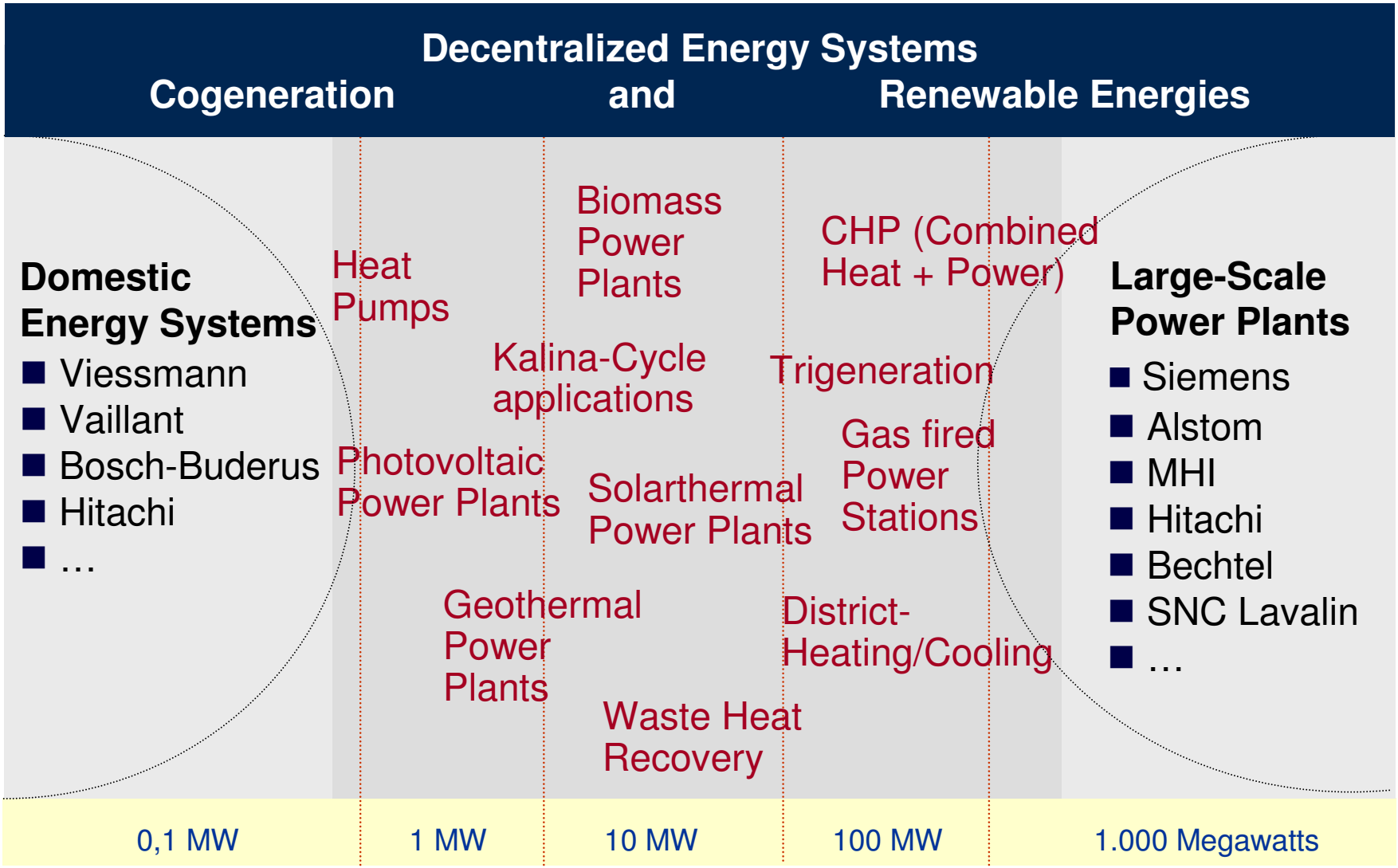
Operation

Facility Management, Operation, Maintenance

- Global Facility Management
- Real Estate Management and Operation
- Maintenance of Technical Building Systems
- Energy and Consumption Management
- Infrastructure Services
- Commercial Services
- Facility Evaluation
- Security Services

Locations Worldwide

Energy Solutions as Turnkey Supplier

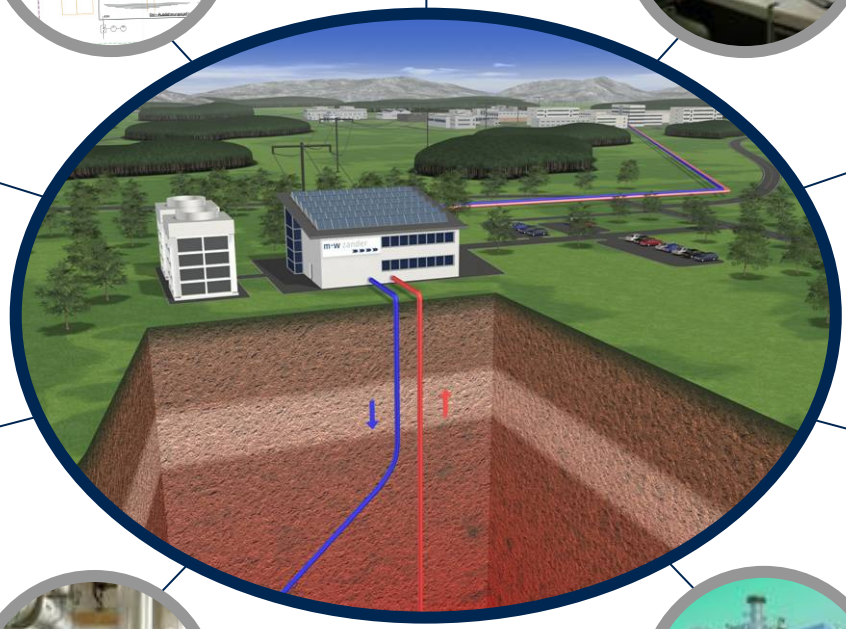


Geothermal Power Plants: Full System Contractor

Consulting Services
Programming
- System Specification
- Environmental Permitting
- Financial Engineering

Operation
- In Line Process Monitoring
- Advanced Process Control
- Web Based Visualization

Design
- Design Development
- Design Reviews



Supply Systems
- N2 Supply Plant
- Water Treatment System

Kalina Cycle
- **Thermodynamic Calculations**
- Heat Exchanger interior Design
- Turbine Specification
- Ammonia-Water Characteristics

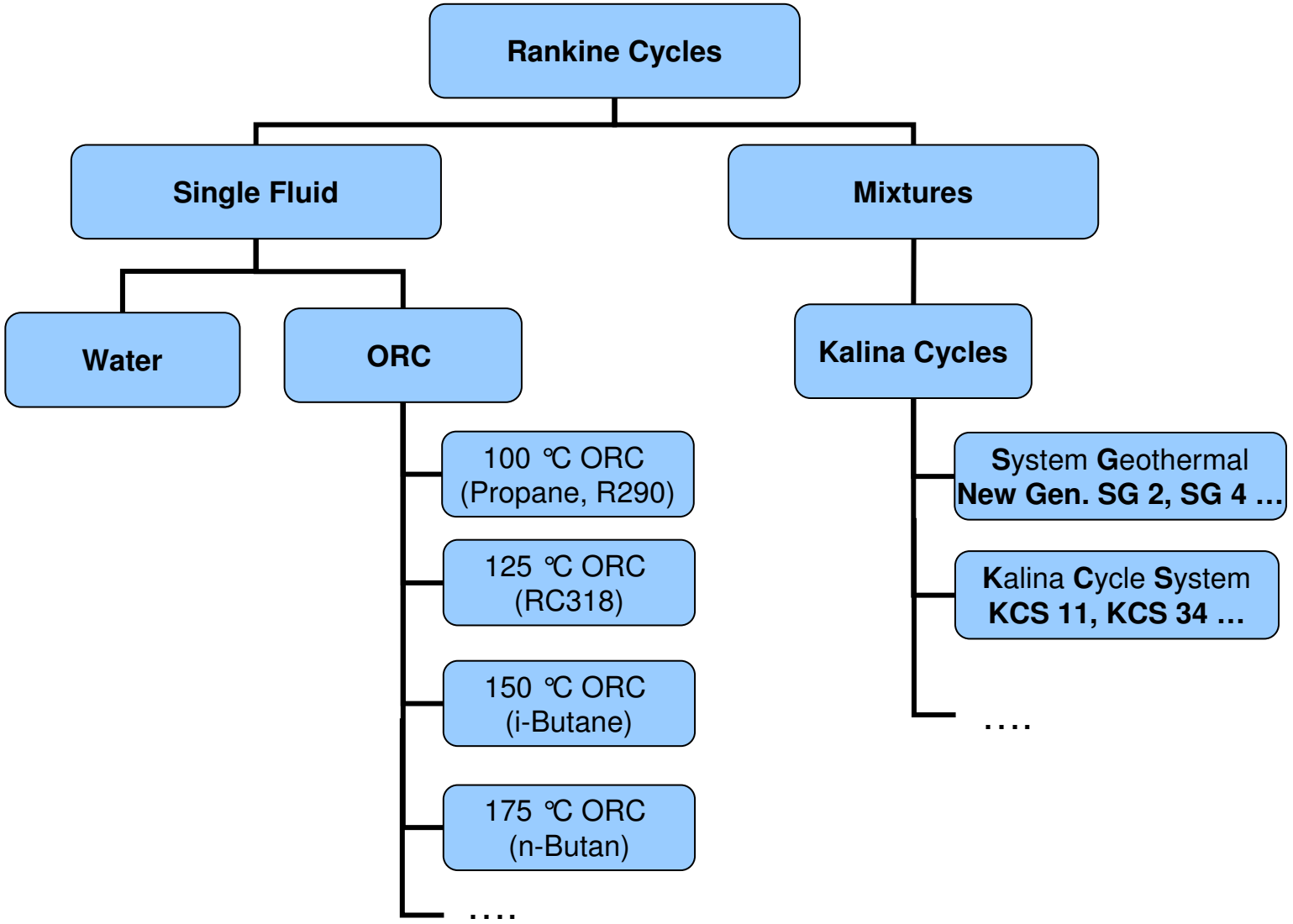
Project Management
- Scheduling
- Cost Control
- Quality Control
- Web Based Project Collaboration

Building and Facilities
- Civil, Structural and Architecture
- Mechanical Systems (air, exhaust)
- Electrical Systems
- Instrumentation and Controls

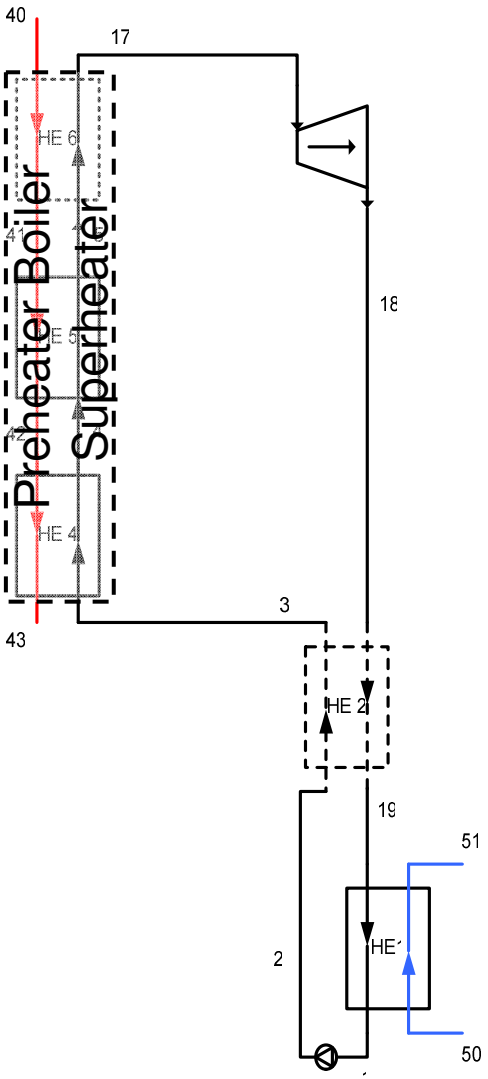
Commissioning and Ramp Up
- Test and Certifications
- Putting into service
- Facility Management Training and Support

Construction
- Construction Management
- Material Logistics
- Installation Services
- Field Engineering

Rankine Cycle Overview

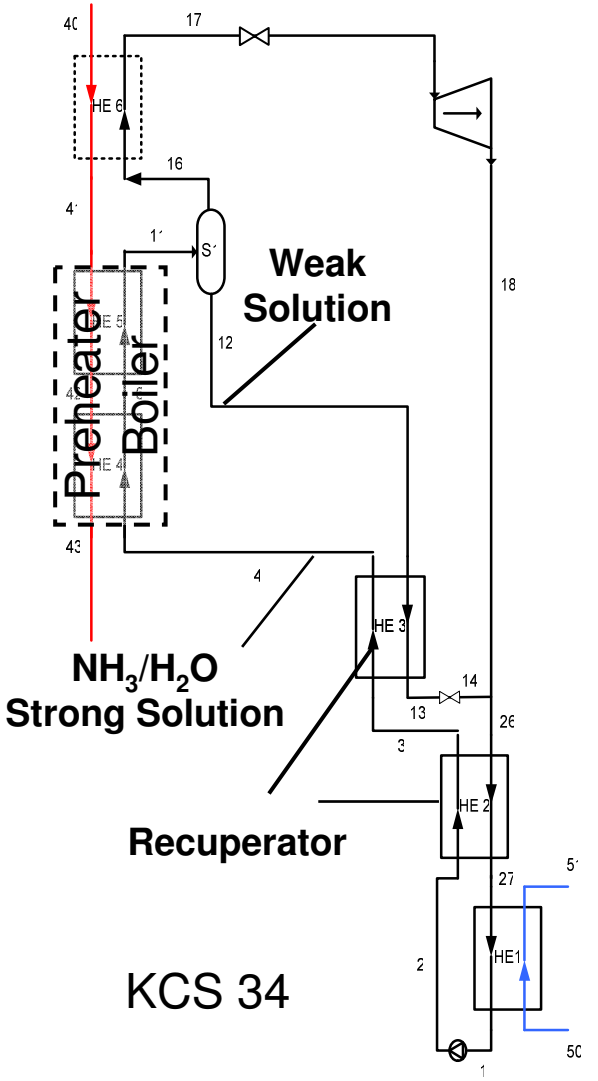


ORC – Kalina Cycle

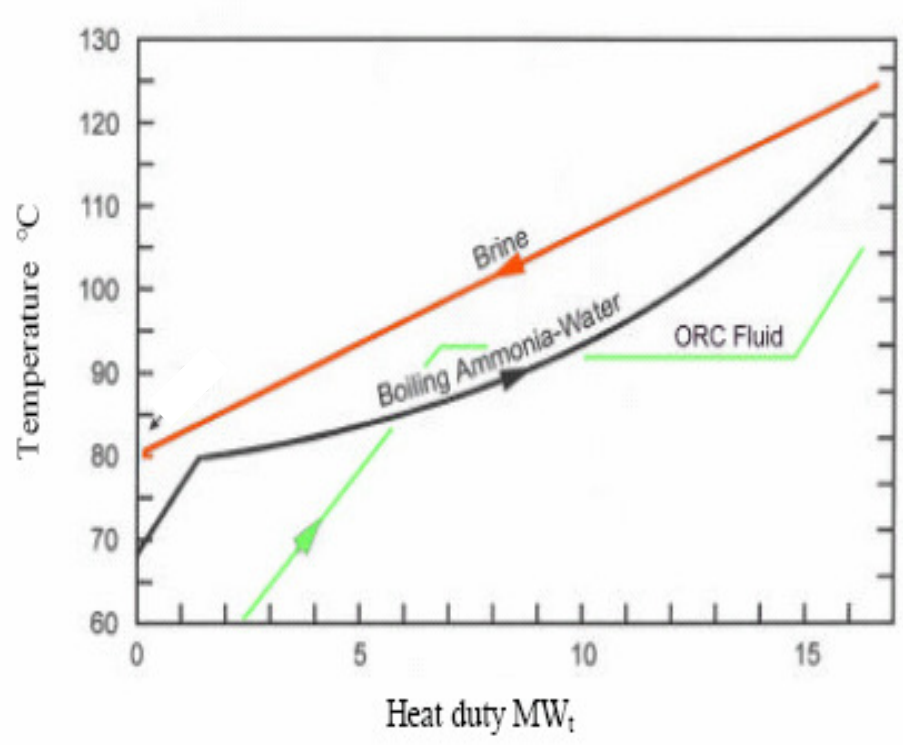


Kalina Cycle compared to ORC

- Single organic working fluid replaced by NH_3/H_2O
- Closed loop of liquid working fluid (strong resp. weak solution)
- Separation of steam and liquid
  Superheating possible but normally not considered in KCS34
- Condensation (absorption) of vapor at low pressure level in 2 steps
- A substantial part of absorption energy may be recuperated to the cycle in HE 2

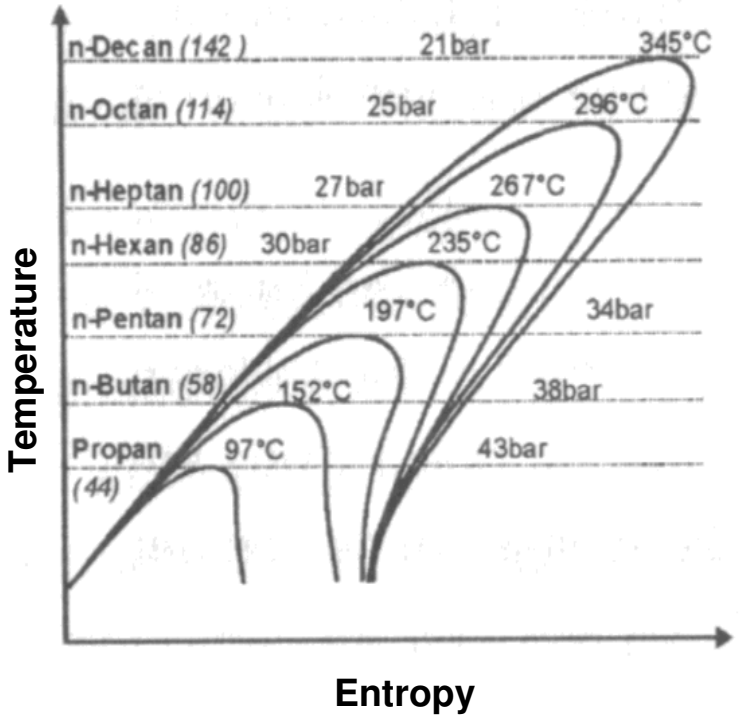


Characteristics of ORC and Kalina Cycles



Evaporation / Desorption Process

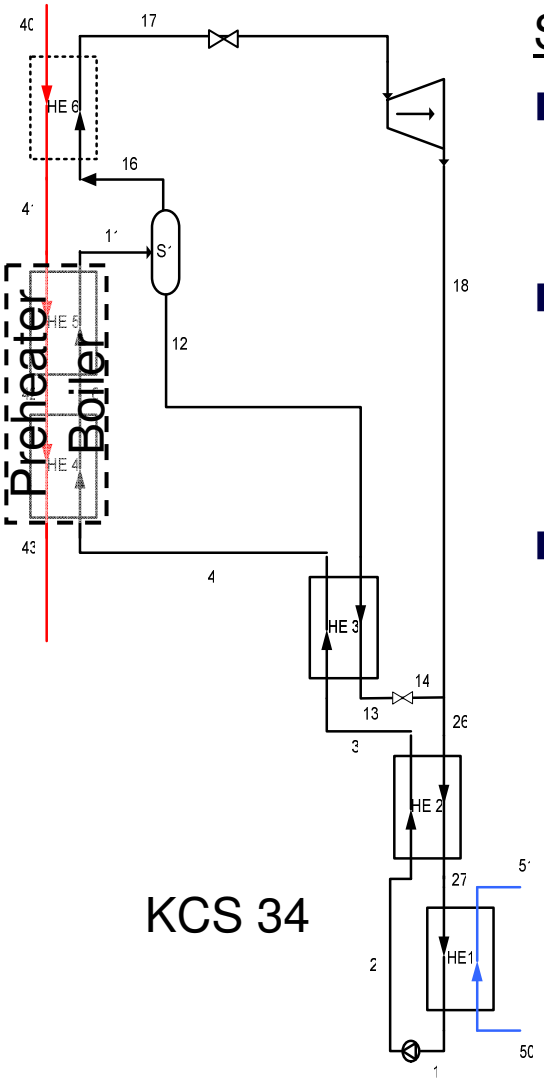
Organic Substances must be selected in accordance to the heat source temperature level ($T_{cr} < T_{in\ Brine}$)



Cycle Caracteristics

- ORC (Single Componant Working Fluid)
  - Evaporation and condensation at fixed temperatures
  - Fluid must be selected in accordance to the temperature level of the heat source
  - Pinch point is limiting factor for heat transfer
  - Environmental impacts and restrictions by using organic substances
    - Inflamable and/or toxic and/or GWP (Global Warming Potential) and/or ODP (Ozone Depletion Potential)
- Kalina Cycle (Mixture of Ammonia/Water)
  - Evaporation (desorption) and condensation (absorption) over a large temperature range (fits to the nature of the heat source)
  - Same working fluid may cover a wide range of the heat source temperature levels $\Rightarrow$ Optimization by switching concentration
  - Ammonia has toxic potential but:
    - Easy to detect at save concentration levels
    - A lot of experiences in handling the substance and operating ammonia cycles (mechanical and absorption chillers)
  - No GWP and ODP

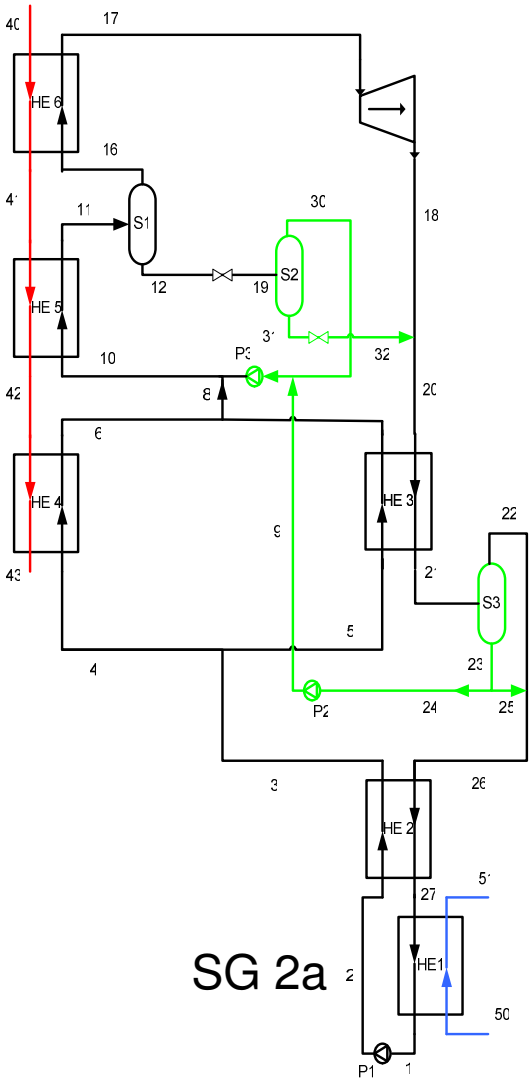
Kalina Cycles KSC 34 and SG 2a



KCS 34

SG2a compared to KSC 34

- Evaporator is splitted in preheater HE 4 and Boiler HE 5
- The working fluid is separated into 2 substreams, preheated in HE 3, HE 4
- Evaporator HE 5 is supplied additionally by an internal cycle, collecting working fluid from separators operating at intermediate and low pressure levels

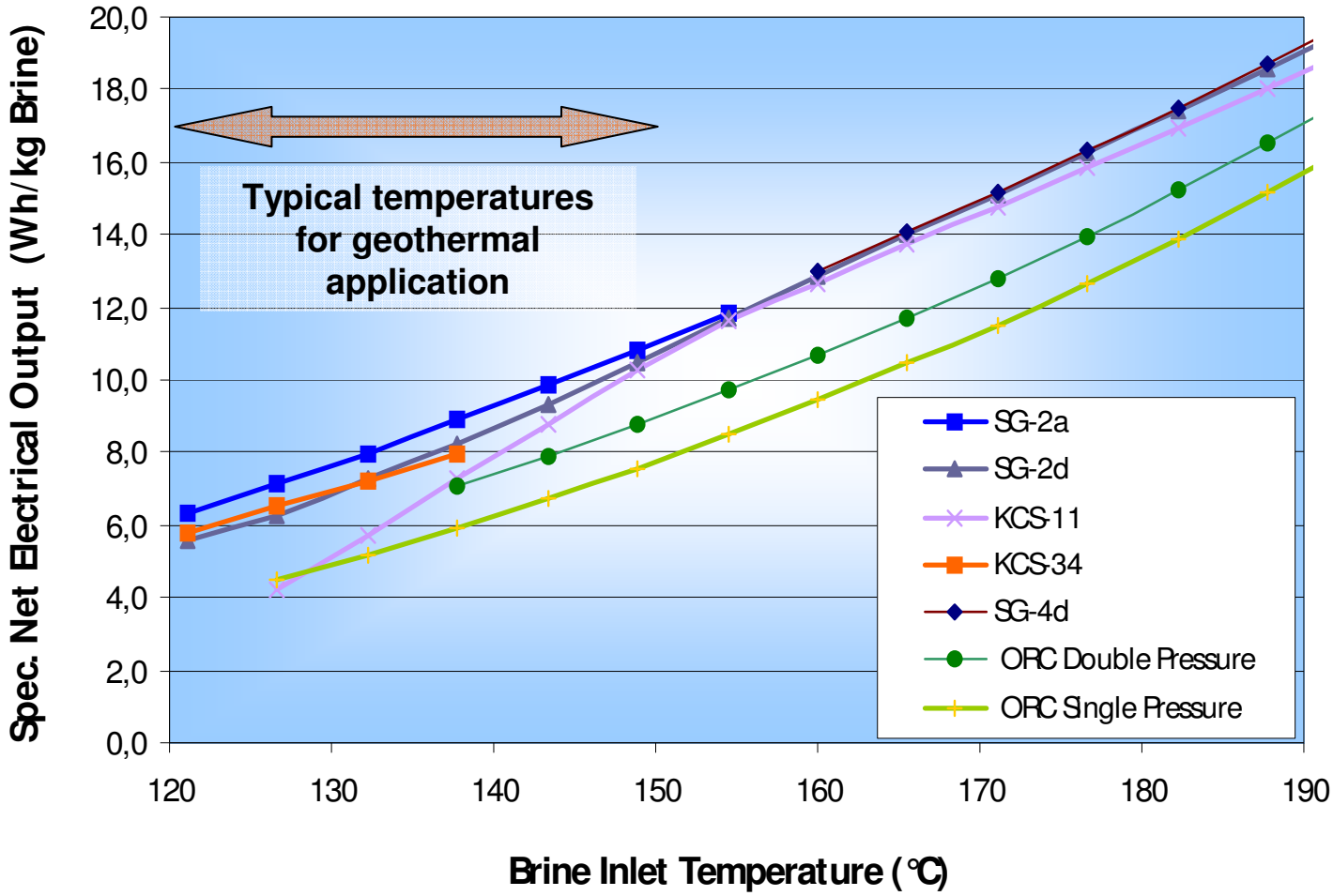


SG 2a

Kalina SG 2a Cycle

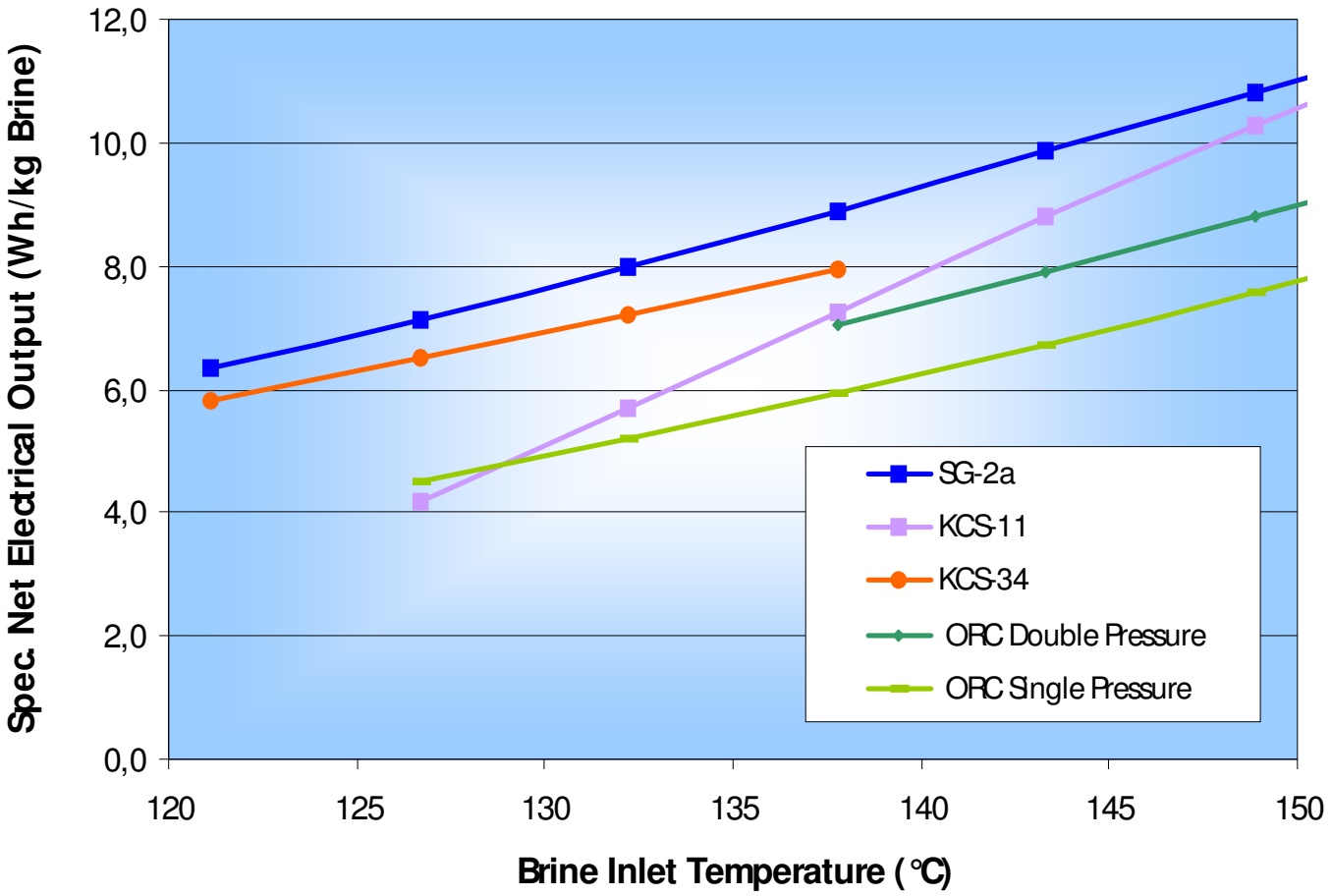
- Increased efficiency, especially at low heat source temperatures (≤ 150 °C)
- Improved adaptability to brine output temperature restrictions (scaling effects)
  - Lower electricity generation loss in case of temperature restrictions
- Enhanced economic and technical viability for the utilization of low temperature geothermal sources
- Additional geothermal energy usage for heating purposes may be performed (e.g. during winter time) at less electrical power losses

Cycle Net Electrical Output Comparison



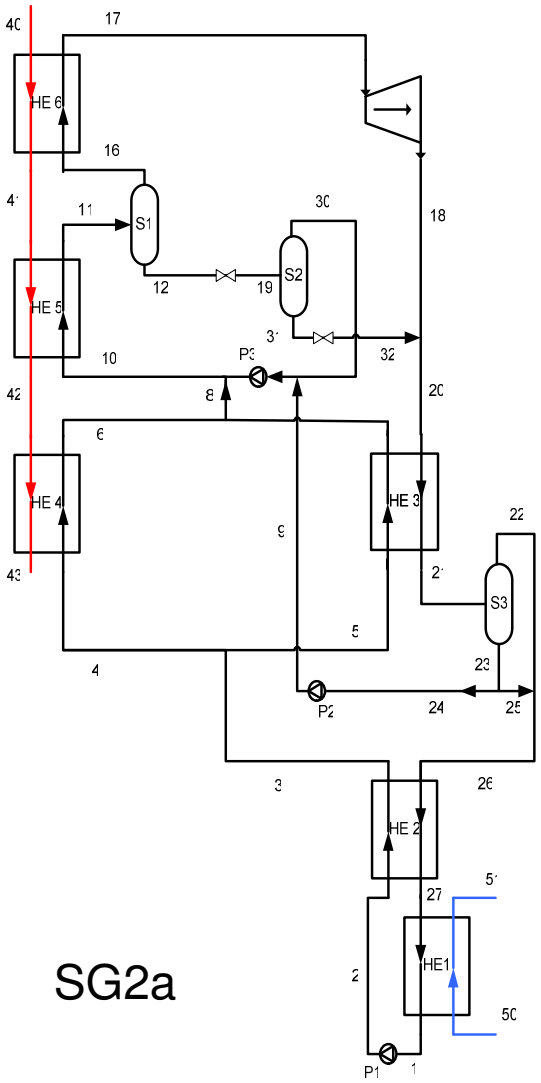
Source: Dr. Alexander Kalina

Cycle Net Electrical Output Comparison



Source: Dr. Alexander Kalina

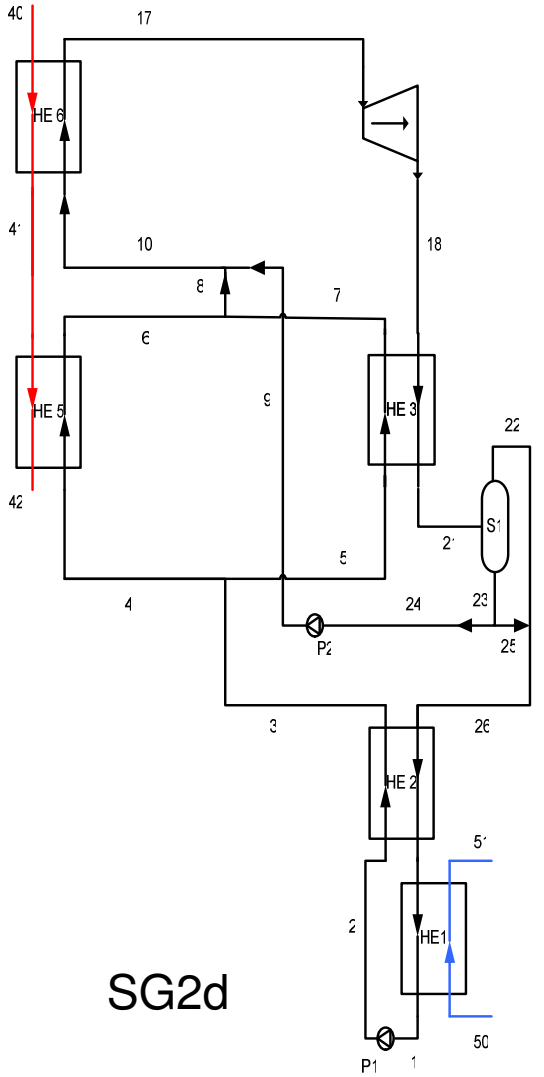
Kalina Cycles SG 2a and SG 2d



SG2a

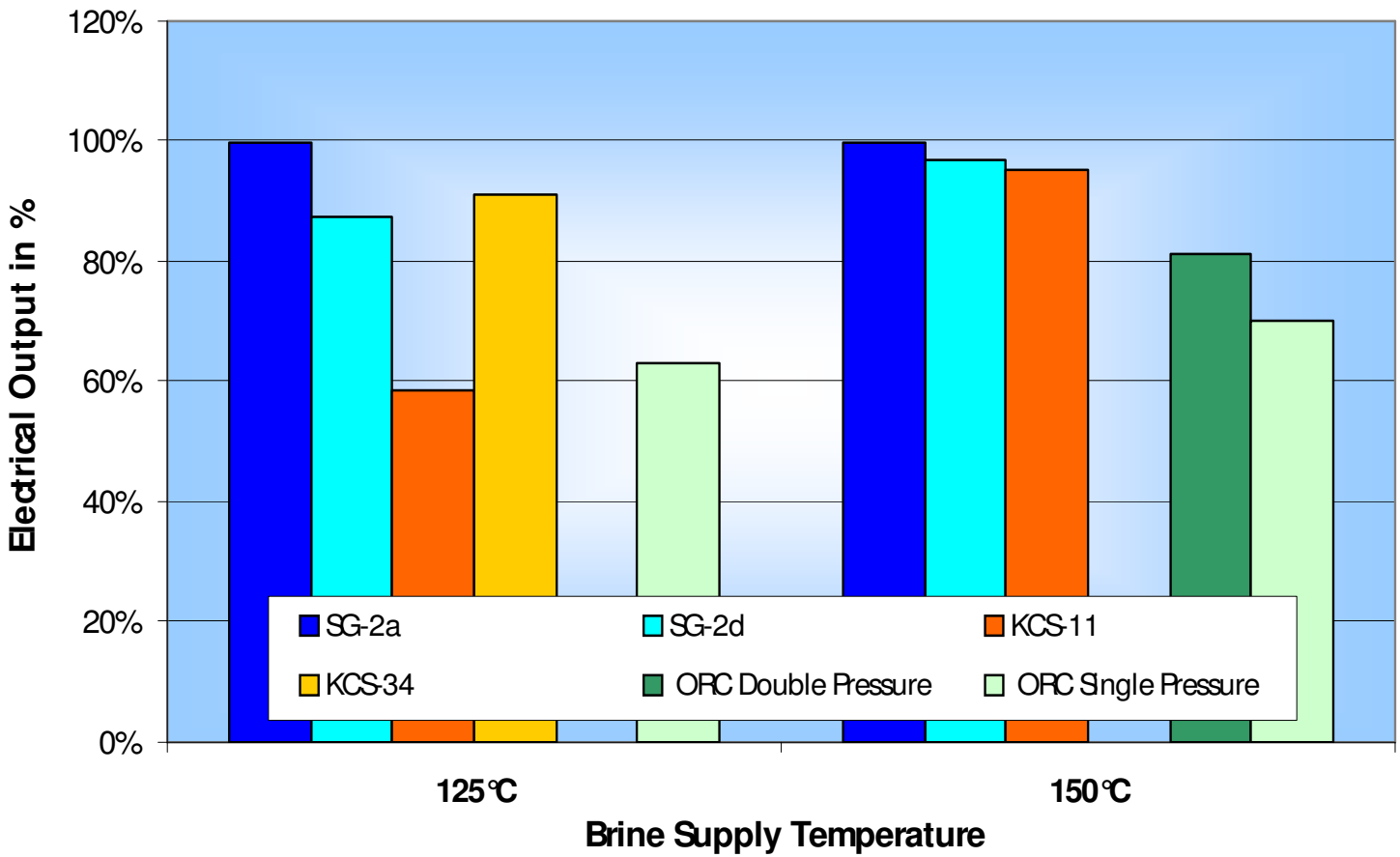
SG2d compared to SG2a

- Working fluid is totally evaporated and slightly superheated in HE 6
- No intermediate pressure level
- SG 2a best performances at temperatures ≤ 150 °C
- SG 2d best performances at temperatures ≥ 150 °C
- SG2d shall be used for high temperature applications



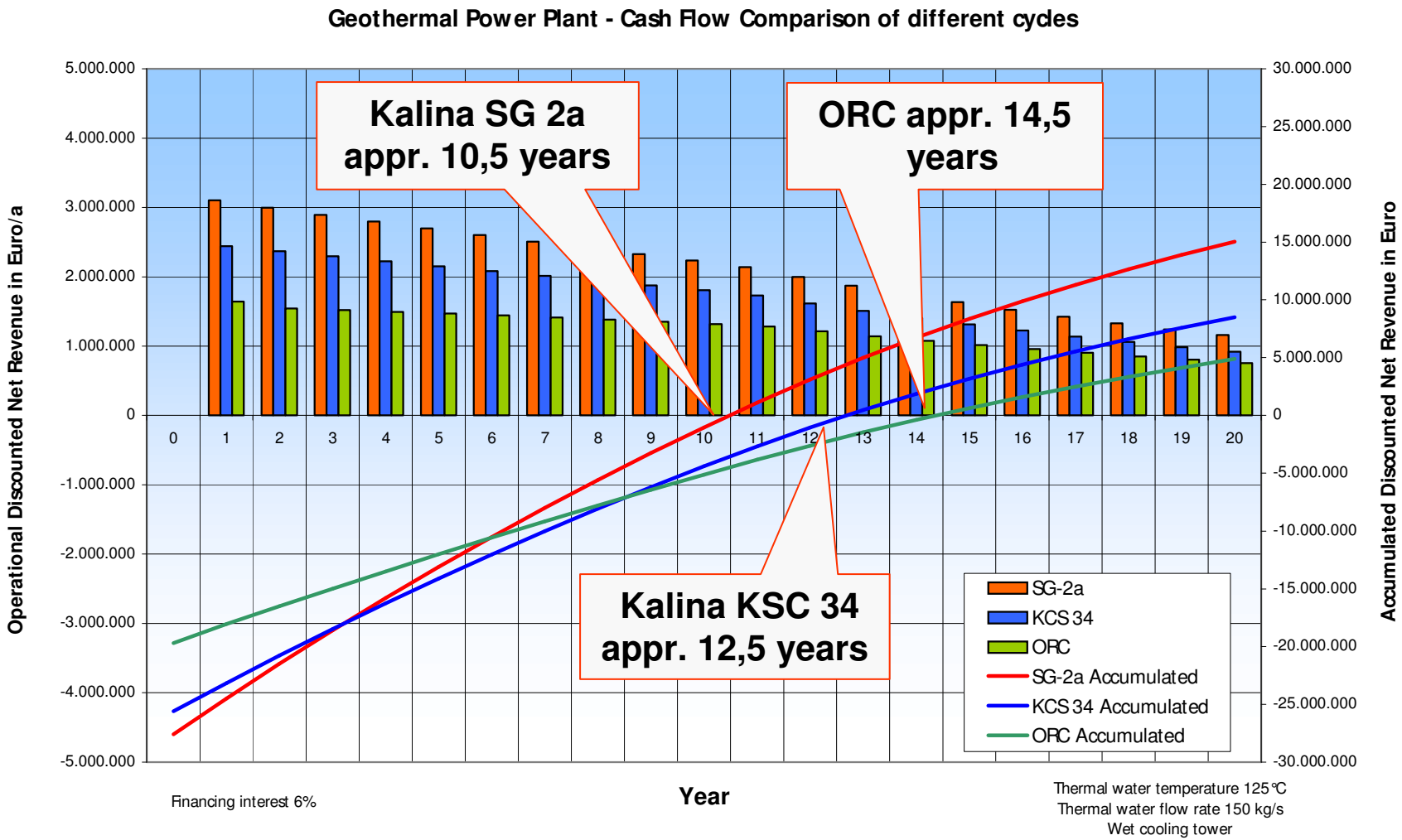
SG2d

Cycle Net Electrical Output Comparison



Source: Dr. Alexander Kalina

Cycle Net Electrical Output Comparison



Cost increase (N2, water, staff, el. power purchase) 2 % p a

Conclusion

- Ammonia water mixture has no GWP and ODP
- New Generation Kalina Cycle SG2a is very flexible concerning project factors (heat source and heat sink adaptation)
- SG2a has the best performance at heat source temperatures ≤ 150 °C
- More sellable electrical energy
- SG2a causes higher invest costs but:
  - ⇒ Higher revenue
  - ⇒ Shorter payback period
  - ⇒ Highest possible economics of a geothermal project