Fritz Kleiner / Steve Kauffman:

All Electric Driven Refrigeration Compressors in LNG Plants Offer Advantages
Reasons to look for improvement

- Gas turbine driven refrigeration compressors require periodic maintenance
- Once shut down, planned or unscheduled, re-starting is time consuming
- LNG train sizes depend on available gas turbine models & ratings

The disadvantages of gas turbines are generic and vendor-independent
Advantages?

| Continuous production is possible for 5...6 years: | Productivity |
| Train size becomes relatively independent of available drivers: | Design flexibility |
| No fired equipment and no scheduled maintenance in process area: | Safety |
| Lower operating costs and greenhouse gas emissions: | Economy |

Significant productivity gains can be realized, plus operating cost & safety improvements
Is the idea really new?

- Large starter-helper motors (VSDS) are already part of every LNG plant
- Turborotor motors have been built up to 65 MW - turbo generators in ratings > 600 MW
- Static frequency converters of the lci type are built in ratings to 3000 MW
- Gas fired power plants with heat recovery are also part of every LNG plant

The All Electric LNG concept does not employ new & unproven technology
All electric drive systems have been built & tested

- Precooling and Subcooling compressor drivers of the Snøhvit project are rated 65 MW each
- Full load back-to-back tests and full-load compressor string tests have been successful
- Liquefaction and boil-off compressors are driven by VSDS rated 32 and 16 MW

Both, motors and variable frequency drives, are available today in ratings up to 90 MW
Modular construction facilitates testing & construction

- Direct outdoor installation inside hazardous area, pluggable cables
- Fully climate controlled and pressurized to exclude the environment
- Multiple individual modules are assembled on-site to form one building
- Safe working environment with one-half of system energized

All drive related electronic and auxiliary equipment can be installed in prefabricated and tested modules
Testing in country of manufacture

- Back-to-back full load & speed tests of identical units possible up to 70 MW
- Full load ASME PTC 10 performance test of compressor string possible
- Combined functional test of power plant, vsds, and compressor control systems

Performance testing of compression strings & control systems in the country of manufacture reveal possible design & manufacturing flaws at an early point
Full load performance testing reduces jobsite risk

- Full load & speed tests for complete compression strings possible at factory
- Design & performance verification prior to shipment
- Actual test conducted in 2004 for Hammerfest LNG *)

*) with Nuovo Pignone compressors at GE test facility in Massa, Italy in June 2004

32 MW motor for pre-cooling compressor

65 MW motor for liquefaction compressor
The associated power plant - simple or combined cycle

- Either is possible - the owners decide on economical criteria
- Power plants suitable for island operation and configured in n+1 design
- With integrated or separate process heat generation

The choice of simple or combined cycle is strictly based on economical factors
The client's priorities determine the type of power plant:

**Combined cycle:**
- Highest efficiency (Low OPEX)
- Lowest emissions
- Better stability during faults

**Simple cycle:**
- Simplest design & construction
- No steam & water circuits ("dry" plant)
- Lowest initial cost (CAPEX)

### Relative Cost and Efficiency

<table>
<thead>
<tr>
<th>Relative Capital Cost</th>
<th>Efficiency</th>
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</thead>
<tbody>
<tr>
<td>100%</td>
<td>~ 52%</td>
</tr>
<tr>
<td>~ 60%</td>
<td>~ 32%</td>
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</tbody>
</table>

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Integrated control systems assure uninterrupted operation

- The loss of a turbo-set in the power plant does not interrupt LNG production
- The stability of the power system is maintained following the trip of a turbo-set

The unscheduled loss of one of the three turbo generators poses the greatest threat to the stability of the liquefaction process. By means of hardware modifications to the power station equipment, and by hi-speed motor-compressor controls this scenario can be managed safely and repeatedly!
Steve Kauffman
Shell Development (Australia)

Electric Drive LNG
A Case Study

What motivated SDA to examine electric drive?

What did we study?

What did we conclude?
Key Value drivers were:

- **Emissions**
  - Harnessing all waste heat
  - Continuous Improvement
  - Positioned for future GHG acts
  - Shell policy & Australian regulatory framework

- **Value**
  - Better asset utilisation
  - Simpler to operate/maintain
  - Lower capex/opex
  - Applicable to other opportunities
LNG concepts studied

Direct Drive

Electric Drive

Study benchmark was 5 mtpa C3MR or DMR configuration

Both concepts having four driver/compressor sets per train
Technological differences are:

Direct Drive

Four drivers/compressors per train

Liquefaction

Precooling

Compressor Casing 1

Gas Turbine Driver

Powergen. Gas Turbines

Thyristor frequency converter

M/G

20 MW Synchronous Motor

Compressor Casing 2

Gas turbine and split casing/axial compressor removed

Electric Drive

Four drivers/compressors per train

Liquefaction

Precooling

Liquefaction

Precooling

Precooling

65 MW Synchronous Motor

M

Larger rating for existing equipment already used in LNG

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Used a medium term horizon

Plateau capacity was identical so that sales volume did not influence assessment
Assessed both quantitative & qualitative factors

- **Economic**
- **Capex/Opex**

- **Reliability/Availability**
  - **HSE**
  - **Safety/Thermal Efficiency**
  - **Future standards**

- **Operations & Maintenance**
  - **Operating window/load shedding**
  - **Refrigerant venting & make-up**

- **Technical Assurance**
  - **Assurance/supplier diversity**

- **Construction**
  - **Pre-assembly**

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Train size tailored to suit opportunity

At 5 mtpa, additional cost <US$ 20M, additional benefits ~ US$ 34M p.a

Direct Drive Datum = 0

Improvement in specific cost $ / t LNG

Limit of Fr7 Direct Drive Train size

Tested result via separate engineering services and independent audit of SGSI cost method/data

Flexible train size, no change to concept

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Achieving Plateau – designing for continuous improvement

- **VALUE** – Capex to achieve maturity – Electric drive was $300M lower

- **EMISSIONS** – Electric drive achieved 750,000 t.p.a lower

Diagram:
- Brownfields expansion to site maturity for each option
- Decide on enhanced energy recovery in D-drive option
- Data for single 5D train
  - For reference

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Summary and conclusion

- Continuous process operation is possible for 6 years with improved utilization of supply chain assets resulting from at least 10 additional stream days
- CAPEX / OPEX improvements offer ~ $100M Net Present Value
- CO2 emissions reduction is in the order of 750 kT/a
- Very little maintenance and no fired equipment in the process area
- Process train sizes of > 5 mtpa benefit most from the E-drive concept, especially if environmental constraints must be observed
- Concept transferable to a variety of train sizes without leaving technology boundaries