**Plan for PhDs in FME HighEFF**

**1. Introductory Statements & Assumptions**

* 20 PhDs should be the minimum, and the budget splits in the Sketch of 1 April provides sufficient funding for these candidates.
* BIGCCS had 18 PhDs and 8 Post.docs (around 23 PhD “equivalents”), and the maximum RCN contribution has been increased from 20 to 30 MNOK/year.
* There are some topics that are best suited for PhD research and some areas where SINTEF research is more appropriate. The distribution of PhDs is reflected by this observation.
* RA5 Society is not well suited for PhD research, but there are several topics that could be suitable for 1-2 Post.docs.
* RA1 Methodologies is well suited for PhD research, and this RA is also well suited for international collaboration. Thus it would be natural to have more PhDs for RA1 than for RA2-RA4.
* In the plan, 2 completely funded PhDs, 1 half funded PhD, and 1 industry funded PhD will be distributed to strategically selected international partners: 1 PhD at MIT, 1 PhD at University of Manchester, 0.5 PhD at CMU and the industry funded PhD at KTH. CMU has indicated considerable interest in such an arrangement (50/50 split of costs).
* The distribution of PhDs on topics and research groups should reflect a concentration of efforts in groups that would have the required momentum for getting results in the HighEFF research areas. This means that the PhDs will not be widely distributed to a large number of individual supervisors.

**2. Topical Groups of Expertise at NTNU**

* Refrigeration Engineering & Heat Pumping: Trygve Eikevik, Armin Hafner and Petter Nekså (Prof.-II) (Energy and Process Engineering)
* Process Systems Engineering: Sigurd Skogestad, Johannes Jäschke (Chemical Engineering), Olav Bolland, Lars Olof Nord, Armin Hafner and Truls Gundersen (Energy and Process Engineering)
* Exergy: Leif Kolbeinsen (Materials Science and Engineering), Signe Kjelstrup (Chemistry), Ivar Ståle Ertesvåg and Truls Gundersen (Energy and Process Engineering)
* Other areas of Expertise with relevance to HighEFF: Power Stations and Combined Cycles (Olav Bolland and Lars Olof Nord), Process Integration and Pinch Analysis (Truls Gundersen), Heat Exchangers (Erling Næss and Armin Hafner), Rotating Machinery (Lars Erik Bakken)

**3. Terms and Definitions**

* Process Systems Engineering (PSE) includes systems oriented (holistic) methods and tools for process analysis (modeling and simulation), process design (synthesis and optimization), and process operation (including control)
* Process Integration (PI) includes integration of heat, power, mass, etc., with methods such as Pinch Analysis and Exergy Analysis

**4. Abbreviations**

CMU Carnegie Mellon University, Pittsburgh

KPI Key Performance Indicator

KTH Royal Institute of Technology, Stockholm

PI Process Integration

PSE Process Systems Engineering

UoM University of Manchester

**5. Distribution of PhDs within RAs and WPs**

5.0 Strategic International Partnerships

* 2 PhDs for NTNU-MIT Collaboration
* 2 PhDs for NTNU-UoM Collaboration
* 2 PhDs for NTNU-CMU Collaboration (CMU PhD funded 50% by CMU)
* 2 PhDs for NTNU-KTH Collaboration (KTH PhD funded by industry)

5.1 RA1 – Methodologies (***7 PhDs***)

* WP 1.1 – Key Performance Indicators (KPI): Signe Kjelstrup (including fundamental research on the use of Exergy for Energy Efficiency): ***1 PhD***
* WP 1.2 – Energy & Exergy Analyses: Truls Gundersen (Work and Heat Exchange Networks): ***1 PhD***
* WP 1.3 – Process Systems Engineering: Sigurd Skogestad and Robin Smith, UoM (Operational Optimization for Energy Savings): ***2 PhDs***
* WP 1.3 – Process Systems Engineering: Truls Gundersen and Paul I. Barton, MIT (Global Optimization for improved Energy Efficiency): ***2 PhDs***
* WP 1.4 – Future Process Framework: Ivar Ståle Ertesvåg (Use of Exergy for Energy Efficiency in new Offshore Frameworks): ***1 PhD***

5.2 RA2 – Components (***3 PhDs***)

* WP 2.1 – Heat Exchangers: Armin Hafner (Compact Heat Exchangers): ***1 PhD***
* WP 2.2 – Expanders & Work Recovery Units: Armin Hafner (Expanders and Ejectors as Novel Components): ***1 PhD***
* WP 2.4 – Natural Working Fluids and Mixtures: Trygve Eikevik (Energy Efficient and Environmentally friendly Working Fluids in Heat Pumps and Refrigeration Cycles): ***1 PhD***

5.3 RA3 – Cycles (***5 PhDs***)

* WP 3.1 – Energy-to-Power Conversion: Lars Olof Nord (Compact and Efficient Bottoming Cycles for Offshore Power Production): ***1 PhD***
* WP 3.1 – Energy-to-Power Conversion: Petter Nekså (Using Pressure and Heat Conversion for Power Production): ***1 PhD***
* WP 3.3 – High Temperature Heat Pumping: Trygve Eikevik (Novel Components and Systems for High Temperature Heat Pumping): ***1 PhD***
* WP 3.4 – Energy Storage: Armin Hafner (Energy Storage for Integration of Renewables, etc.): ***1 PhD***
* WP 3.4 – Energy Storage: Sigurd Skogestad (Optimal Operation and Control of Energy Storage Systems): ***1 PhD***

5.4 RA4 – Applications (***6 PhDs***)

* WP 4.1 – Process Improvements: ***N.N. (IMT)*** (One the Way to Closed Furnaces in the Metallurgical Industry): ***1 PhD***
* WP 4.2 – Surplus Heat Recovery: Petter Nekså and Lundqvist/Palm, KTH (Novel Energy Recovery Concepts): ***2 PhDs*** (KTH PhD funded by industry)
* WP 4.3 – Technology Integration: Johannes Jäschke and Lorenz T. Biegler, CMU (Integration and Optimization of New Technologies in an existing Processing Plant): ***2 PhDs***  (CMU PhD 50% funded by CMU)
* WP 4.4 – Industry Clusters/Grids: Leiv Kolbeinsen (Use of Smart Thermal Grids in Industrial Clusters for improved Energy Efficiency): ***1 PhD***

5.5 RA5 – Society (***1 Post.doc***)

* WP 5.1 & 5.2 – Innovation & Roadmaps, Barriers & Enablers: ***N.N. (where)*** (A study of Barriers & Enablers for improved Energy Efficiency while considering Innovation and Roadmaps): ***1 Post.doc***

5.6 Summary of Researcher Recruitment

* RA1: 7 PhDs
* RA2: 3 PhDs
* RA3: 5 PhDs
* RA4: 6 PhDs
* RA5: 1 Post.doc
* Grand Total: ***21 PhDs*** and ***1 Post.doc***
* Externally funded: 1.5 of the 21 PhDs

**6. Distribution of PhDs/Post.docs among Supervisors** (+ for international PhDs)

* Armin Hafner: 3
* Sigurd Skogestad: 2 + 1
* Petter Nekså: 2 + 1
* Truls Gundersen: 2 + 1
* Trygve Eikevik: 2
* Johannes Jäschke: 1 + 1
* Leiv Kolbeinsen: 1
* Lars Olof Nord: 1
* Ivar Ståle Ertesvåg: 1
* Signe Kjelstrup: 1
* N.N. (IMT): 1 (Closed Furnaces in Metallurgical Industry)
* N.N. (where): 1 Post.doc (RA5 Society)
* Grand Total: ***21 PhDs*** and ***1 Post.doc***

**7. Distribution of PhDs/Post.docs among NTNU Departments**

* Energy and Process Engineering: 11 + 2
* Chemical Engineering: 3 + 2
* Materials Science and Engineering: 2
* Chemistry: 1
* N.N.: 1 Post.doc (RA5)
* Grand Total: ***21 PhDs*** and ***1 Post.doc***

Trondheim,

16 November 2015

Truls G.