



A Co-ordination Action funded by the European Commission, Sixth Framework Programme under Priority 6; Sustainable development, global change and ecosystems



## MicroCHeaP Progress Update

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MicroCHeaP is a European Commission funded Co-ordination Action which aims to stimulate and facilitate technology transfer between cutting-edge researchers and industries in the renewable micro-CHP industry, with the view of optimising its efficiency, cost-effectiveness, and market size, and hence boost the development of a sustainable energy infra structure. It will evaluate technologies and research in the field of micro-CHP and renewable energy systems, with the aim of technological integration and the stimulation of research and development of new renewable micro-CHP technologies. The project results will then be disseminated directly to target clients and also to a wider audience. The project began in October 2004 and is now in its 22<sup>nd</sup> month.

### Progress so far

**Literature and Patent Search:** A literature and patent search was conducted in the first six months of the project. This addressed a range of renewable technologies and CHP systems and formed the basis for the State of the Art and Market Review, which was subsequently produced. Both the literature review and the patent search will be updated at intervals throughout the project.

**State of the Art and Market Review:** A state of the art and market review has been produced. This details the latest developments in the field of renewable micro-CHP and related subjects. It also presents an overview of the market conditions and trends in a number of European countries allowing market gaps and barriers to the implementation of renewable micro-CHP to be identified.

**Co-ordination Seminars:** The project holds annual co-ordination seminars to discuss the state of current research amongst the partners. Members provide an overview of current research interests, in order to make partners

aware of other work being carried out in the field. The knowledge gained from this seminar has been valuable to partners and has allowed them to make inputs to other ongoing projects, which has hopefully helped to avoid the duplication of research efforts.

**Web Site:** The project web site ([www.microcheap.org](http://www.microcheap.org)) is a key communication tool of the project. It contains detailed information as well as forthcoming events and results from the project.

**Expert Group Discussions:** Three expert groups have been decided upon, which will meet at regular intervals throughout the project with the aim of; identifying gaps in current research, discussing and exchanging information and know-how on common themes of interest and hearing lectures from invited speakers. The three expert group topic areas are:

- Technologies
- Integration
- Fuels

The first discussions were held in March 2005, the second in April 2006 with future meetings planned for March 2007.

**Topical Seminars:** The project has held two topical seminars. These are designed to raise awareness of new technologies and also to inform members of other partners expertise. The two seminars were titled,

- Review of marketable, near-to-market and far-from-market RES-Micro-CHP
- Methodology of marketing RES-Micro-CHP

### 3<sup>rd</sup> MicroCHeaP Coordination Seminar on Micro- CHP

21<sup>st</sup> – 22<sup>nd</sup> September  
NTUA, Athens,  
Greece

If you are interested in  
attending this event  
please contact:  
[Robert@chalex.com](mailto:Robert@chalex.com)

**Mapping of Research Activities:** A list of established industrial companies, university research groups and public and private research organisations active in RTD relevant to renewable micro-CHP across the EU has been produced. The information will be compiled into an internet database which will be accessible from the project website and will include the ability to rank the research groups and industrial companies based on number of publications, number of patents, number of licence agreements, number of citations, number of PhD theses, number of breakthroughs and academic awards. Key research areas will be identified, as well as possible gaps, and corrective strategies for new research activities will be elaborated.

**Technology Transfer Workshop:** A very successful technology transfer workshop was held in April 2006. This addressed three main topics:

- Instruments, methods, financing for Micro-CHP technology transfer
- Best available technologies, outstanding projects, most promising near market technical research results from Micro-CHP-poly generation technologies
- Demand-driven decentralized energy supply using Micro-CHP, micro poly-generation systems powered by renewable energy carriers

The workshop was attended by many participants from outside the consortium including representatives from; the gas and electric supply industry in Denmark (Essent), micro-CHP developers (ENERTEC and Danfoss), the dutch gas supplier (GASUNIE), the German CHP producer (SENERTEC) and the renewable energy partnership (Renergiepartner). See below for a detailed report on the workshop. A second technology transfer workshop is scheduled for March 2007 (to receive details of this and future events register your interest at [www.microcheap.org](http://www.microcheap.org)).

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## The MicroChEaP Consortium

- Chalex Research Ltd.
  - Sustainable Technology Solutions Ltd.
  - FORCE Technology
  - EA Technology Ltd.
  - École Nationale Supérieure des Mines de Paris – Centre Energétique
  - Deutsche Gesellschaft für Sonnenenergie e.V.
  - Enervac-Flutec Ltd.
  - WBI Technology Ltd.
  - Energy Research Centre of the Netherlands
  - Aston University
  - Lunds Universitet
  - The Centre of Renewable Energy Sources
  - Biomass Technology Group B.V.
  - Fördergesellschaft Erneuerbare Energien e.V.
  - Gaia Group Oy
  - National technical University of Athens
  - Technology Codes Ltd.
  - Energy Consulting Network
  - Fraunhofer Institut Solare Energiesysteme
  - Institut Für Solare Energieversorgungs Technik e.V.
  - Università' IUAV di Venezia
  - Ålborg University Esbjerg
  - ÅF Group
  - Universitat de Barcelona
  - BEAMA Ltd.
  - Slovenská Poľnohospodárska Univerzita v Nitre
-

## MicroCHeaP 1<sup>st</sup> Technology Transfer Workshop

The 1<sup>st</sup> MicroCHeaP Technology Transfer Workshop was held in Petten in the Netherlands on 6<sup>th</sup> April 2006 and was hosted by ECN. The event was very successful and was attended by 40 participants including partners from the MicroCHeaP project, as well as representatives from various industrial bodies and DG TREN.

The workshop began with an introductory presentation given by Ivo Opstelten of ECN, on behalf of his colleague Gerrit Jan Schaeffer who was unable to attend, this focused on the importance of micro-CHP as a stepping stone towards a distributed sustainable energy system and provided an excellent starting point for the rest of the workshop.

The workshop was split into three sections, the first of these was titled, 'Instruments, methods, financing for Micro-CHP technology transfer' and the first presentation in this section was given by Andreas Heinz, of DG TREN. This presentation highlighted the important role that the EC plays in supporting the development of micro-CHP through both legislative action but also through programmes of technological advancement and market penetration. Eberhard Oettel then gave an excellent presentation on instruments, methods and financing for RES-micro-CHP and he was followed by Henri Giessen, from the Dutch energy company Essent. Who discussed the idea of virtual storage of energy on the grid as a way of encouraging the uptake of micro-CHP technology in homes. A discussion session followed and this ended the first section of the workshop.

The second section was titled, 'Best available technologies, outstanding projects, most promising near market technical research results from Micro-CHP-poly generation technologies.' Jan Muller from ISET, kicked off this section of the workshop by discussing Stirling engines for use in Micro-CHP. Gary Beckers from Enatec also gave a presentation looking at Stirling engine based technology specifically discussing the development of a DCHP unit based on a free piston Stirling engine. Mads Nielsen from Force Technology gave an excellent presentation describing the work of the Green Fuel Cell project which aims to produce a gas that can meet the requirements for fuel for solid oxide fuel cells through reliable, up-scalable and cost-effective staged gasification of biomass. Jari Hiltunen from Gaia Consulting discussed energy management for fuel cells. Christoph Hildebrandt from S&R gave an overview of the Inhouse 4000 team and its aims and activities. Per Balslev from Danfoss talked about the national demonstration project looking at Micro-CHP systems based on Danish fuel cell stacks. Other presentations in this section included Jan Willem Turkstra from Gasunie discussing smart power systems, SenerTec outlining the DACHS CHP unit, Jan Muller discussing microturbines, Renergie reporting on the field tests of the Lion-Powerblock, Elma Gyftopoulou discussing fast pyrolysis of biomass.

The third section titled, 'Demand-driven decentralized energy supply using Micro-CHP, micro poly-generation systems powered by renewable energy carriers', began with a presentation by Yannis Vougiouklakis from Cres discussing end-user attitudes towards micro-CHP and this was followed by Maarten Hommelberg discussing integrating Micro-CHP into distributed energy systems with the PowerMatcher. This closed the third section.

The final section of the workshop was titled, 'Potentials of Micro-CHP systems, needs and demands in the overall European Renewable Energy Strategy and sustainable living strategy, beyond the Kyoto protocol goals' Jens Bo Holm-Nielsen from Aalborg University gave a presentation looking at the predicted bio-energy potentials in the EU25 and the world.

Each section was followed by a discussion section and these were found to be very productive.

It is anticipated that the 2<sup>nd</sup> Technology Transfer Workshop, which is scheduled to be held in March 2007, will build on the success of this first event and aim to attract an even larger audience. For more information regarding forthcoming events relating to the MicroCHeaP project go to [www.microcheap.org](http://www.microcheap.org).



MicroCHeaP 1<sup>st</sup> Technology Transfer Workshop, Petten



MicroCHeaP 1<sup>st</sup> Technology Transfer Workshop, Petten



MicroCHeaP 1<sup>st</sup> Technology Transfer Workshop, Petten

# Assessment of biogas production in dependence on the use of various biomass co-substrates

By Ján Gaduš

## INTRODUCTION

To increase the biogas production or the methane volume in the biogas it is used to add some kind of co-substrate into the biomass. The most common situation is when a major amount of a main basic substrate (e.g. manure or sewage sludge) is mixed and digested together with a minor amount of one or more additional co-substrates. Moreover co-fermentation has become a multi-purpose process serving at the same time for waste upgrading, energy production, improvement of fertilizer quality and other purposes.

Very important in co-fermentation process is to pay attention to both quantity and quality of the added co-substrates to ensure a continuity of the anaerobic digestion process. Therefore one should know the composition of the added co-substrates as well as the necessary duration of the biomass stay in digester to reach an adequate digestion of the organic materials contained in it and the maximal allowable load of the digester. One of the international projects dealing with co-fermentation issues was the European project **AMONCO - Advanced prediction, monitoring and controlling of anaerobic digestion processes behaviour towards Biogas usage in Fuel Cells** (5<sup>th</sup> FP, Project N° NNE5-2001-00067). Slovak University of Agriculture in Nitra was one of the project partners and its demonstration biogas plant in Koliňany (for more details on the biogas plant see the MicroCHeaP Newsletters – Edition 1) served as a venue for experiments with anaerobic digestion of mixtures consisting of cattle manure and various biomass co-substrates.

## OBJECTIVES OF THE EXPERIMENTS

A main goal of the AMONCO project was advanced prediction, monitoring and controlling of anaerobic digestion processes behaviour towards biogas usage in fuel cells. In relation to these goal there were carried out experiments with co-fermentation of animal biomass mixed with energy crops and kitchen waste. The cattle manure was consequently mixed with corn silage, fresh grass, kitchen waste and grass silage. These long-term experiments were done from November 2003 up to November 2004. During this period one monitored composition of input substrate samples, composition of substrate samples taken from the digester and composition and quantity of the produced biogas. The observed parameters are overviewed in the Table 1.

	MEASURED PARAMETERS
<b>INPUT SUBSTRATE</b>	COD - chemical oxygen demand OLR - organic loading rate TS - total solid SO <sub>4</sub> <sup>2-</sup> - sulphate N <sub>total</sub> - total nitrogen
<b>SUBSTRATE FROM DIGESTER</b>	TS - total solid VSS - volatile suspended solid NH <sub>4</sub> <sup>+</sup> - ammonia nitrogen VFA - volatile fatty acids t - temperature pH
<b>BIOGAS</b>	CH <sub>4</sub> - methane CO <sub>2</sub> - carbon dioxide H <sub>2</sub> S - hydrogen sulphide P <sub>G</sub> - biogas production

Table 1 Parameters observed during the co-fermentation process

An experiment with pure cattle manure served as a reference one. Duration of the particular cycles of the experiments is given in the Table 2.

CYCLE	USED SUBSTRATE	DURATION	
I	100 % vol. cattle manure	21.11.2003 08.03.2004	–
II	40 % vol. cattle manure, 60 % vol. corn silage	23.03.2004 23.04.2004	–
III	60 % vol. cattle manure, 40 % vol. corn silage	24.04.2004 26.05.2004	–
IV	90 % vol. cattle manure, 10 % vol. fresh grass	07.06.2004 19.07.2004	–
V	92,3 % vol. cattle man., 7,7 % vol. kitchen waste	04.08.2004 20.09.2004	–
VI	90 % vol. cattle manure, 10 % vol. grass silage	27.09.2004 18.11.2004	–

Table 2 Duration of the particular cycles of the experiments with co-fermentation process

## MATERIAL AND METHODS

For the purposes of the AMONCO project there was built a special 5 m<sup>3</sup> pilot fermentor composing the experimental facility together with a homogenisation tank, co-mixture tank for co-fermentation mixture preparation, biogas holder and storage tank of the digested sludge used for the biogas production. A scheme of the experimental biogas production facility is shown on the Fig. 1.

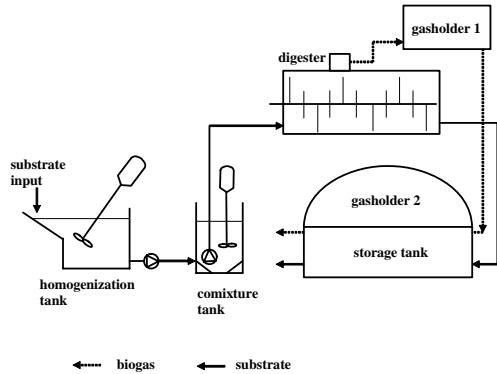


Fig. 1 Scheme of the experimental facility for biogas production

As the figure 1 shows, cattle manure is fed to the substrate input homogenization tank, in which it is adulterated at need and homogenized by means of a propeller mixer. A mixture needed for the co-fermentation process is prepared in the next homogenization tank, where it is treated by means of a vertical mixer. Once a day, the prepared mixture is overdrawn into the digester. The digester is a main technological part of the biogas production facility. It ensures heating and mixing of the biomass substrate during the whole anaerobic digestion process. After an addition of the fresh substrate daily amount, the same amount of the decomposed substrate is removed through a flow-off, situated in the back part of the digester, into a storage tank of the decomposed substrate. The produced biogas is collected in a gasholder in the upper part of the digester and due to own excess pressure it is treaded out through a distributing pipeline into the gasholder.

## RESULTS OF THE EXPERIMENTS

One of the main characteristics related to the composition of the input substrate is a value of chemical oxygen demand (COD), which is directly proportional to the total amount of organic compounds contained in the substrate which is theoretically possible to convert into the biogas. From the COD value the organic loading rate is calculated according the formula:

$$OZF = \frac{CHSK (kg \cdot m^{-3})}{V_F (m^3) \cdot 24}, (kg \cdot CHSK \cdot m^{-3} \cdot h^{-1}) \quad (1)$$

where  $V_F$  - digester volume, m<sup>3</sup>

Influence of the organic loading rate on the biogas production is presented in Fig. 2 – 4, showing the courses of organic loading rate and biogas production during the co-fermentation processes with substrates prepared from the corn silage, kitchen waste and grass silage added into the cattle manure. Excessive load of the digester by organic compounds can lead to an inhibition effect and even to a breakdown of the anaerobic digestion process.

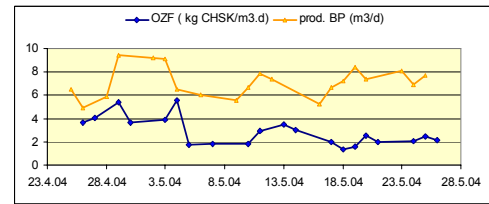


Fig. 2 Record of the digester organic load and biogas production per day during co-fermentation of the mixture consisting of cattle manure and corn silage (40:60)

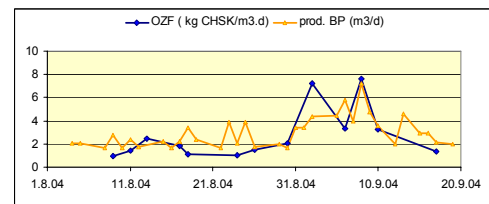


Fig. 3 Record of the digester organic load and biogas production per day during co-fermentation of the mixture consisting of cattle manure and kitchen waste

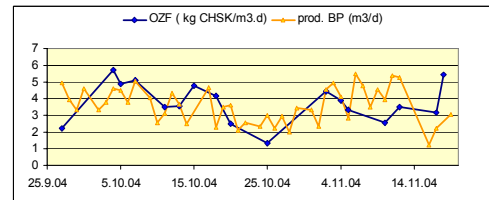


Fig. 4 Record of the digester organic load and biogas production per day during co-fermentation of the mixture consisting of cattle manure and grass silage

All measured data were processed with the use of the descriptive statistics and average values of all the observed parameters are presented in the Tables 3 – 5.

Sulphate emissions are not a direct threat to the environment, but high sulphate concentrations can cause an imbalance in the natural sulphur cycle. Sulphide production can present serious operational problems in anaerobic reactors used for the treatment of waste waters containing high sulphate concentrations. Hydrogen sulphide (H<sub>2</sub>S) in aqueous and gaseous solution causes chemical (corrosion, odour, increase of the effluent COD) and biological (toxicity, inhibition) problems that can affect the anaerobic digestion process.

A carbon - nitrogen ratio of about 30 ÷ 1 is ideal for the raw material fed into a biogas plant. A higher ratio will leave carbon still available after the nitrogen has been consumed, starving some of the bacteria of this element. These will in turn die, returning nitrogen to the mixture, but slowing the process. Too much nitrogen will cause this to be left over at the end of digestion (which stops when the carbon has been consumed) and reduce the quality of the fertiliser produced by the biogas plant.

CYCLE	USED SUBSTRATE	COD mg.l <sup>-1</sup>	OLR kg COD.m <sup>-3</sup> .d <sup>-1</sup>	TS %	N <sub>total</sub> mg.l <sup>-1</sup>	SO <sub>4</sub> <sup>2-</sup> mg.l <sup>-1</sup>
I	100 % CM	45508	3,19	4,82	93,1	191,3
II	40 % CM + 60 % CS	53208	3,12	5,29	91,7	60,3
III	60 % CM + 40 % CS	54700	2,86	5,98	114,2	48,6
IV	90 % CM + 10 % FG	47750	1,85	4,92	86,5	41,8
V	92,3 % CM + 7,7 % KW	41769	2,7	3,59	59,6	61,6
VI	90 % CM + 10 % GS	61535	3,77	5,2	105,4	66,0

where:

- CM - cattle manure
- KW - kitchen waste
- CS - corn silage
- GS - grass silage
- FG - fresh grass

Table 3 Results of the analyses of the input substrate samples

CYCLE	USED SUBSTRATE	TS %	VSS %	VSS % TS	NH <sub>4</sub> <sup>+</sup> mg.l <sup>-1</sup>	VFA mg.l <sup>-1</sup>	pH	t °C
I	100 % CM	-	-	-	808	-	7,05	37,5
II	40 % CM + 60 % CS	4,87	3,46	70,47	835	1148	7,19	38,68
III	60 % CM + 40 % CS	4,45	3,37	76,54	551	1150	6,92	37,92
IV	90 % CM + 10 % FG	4,87	3,46	70,47	835	1148	7,19	38,68
V	92,3 % CM + 7,7 % KW	8,34	3,50	43,52	627	769	7,50	36,71
VI	90 % CM + 10 % GS	7,54	3,92	51,87	598	1483	7,43	37,73

Table 4 Results of the analyses of substrate samples taken from the digester

CYCLE	USED SUBSTRATE	CH <sub>4</sub> (% vol.)	CO <sub>2</sub> (% vol.)	H <sub>2</sub> S (ppm)	P <sub>e</sub> (m <sub>N</sub> .d <sup>-1</sup> )
I	100 % CM	55,77	39,07	158	4,8
II	40 % CM + 60 % CS	55,6	41	53	8,29
III	60 % CM + 40 % CS	55,1	44	141	7,126
IV	90 % CM + 10 % FG	55,4	44,5	81	1,273
V	92,3 % CM + 7,7 % KW	59	41	319	2,97
VI	90 % CM + 10 % GS	56,7	43	338	3,6

Table 5 Results of the biogas samples analyses and biogas daily production

Increase of the pH value caused by an excessive NH<sub>3</sub>

production from proteins is another important inhibition factor. The NH<sub>4</sub><sup>+</sup> inhibition factor makes itself felt according (Andreas, 1998) at a volume above 2500 mg.l<sup>-1</sup> and the toxicity even at the values above 12 000 mg.l<sup>-1</sup> while the volume of the free ammonia was not higher than 80 mg.l<sup>-1</sup>. Under certain conditions also volatile fatty acids (VFA), which are an intermediate product of the acidogenous phase of the digestion, can have inhibition and toxic impacts.

In the biogas methane is the main energy holder. Hydrosulphide combustion generates allied substances SO<sub>x</sub>, which in an interaction with water create sulphate acids, and which have corroding effects on metallic elements.

Courses of the biogas production in the particular cycles of the experiments with co-fermentation are represented in the Fig 5. As it results from the graph given in Fig. 5, the biogas production increased only in the case of manure - corn silage co-fermentation. In the other cases a decrease of the biogas production was registered. The fermentation of the manure with fresh grass led almost to a total breakdown of the biogas production. But after some time the biogas production started to rise, what means that at a changeover from pure manure fermentation to co-fermentation necessary adaptation period of methanogenic bacteria is a longer one than the time duration of the particular experimental cycles. Therefore to compare an average biogas production, the Table 3 presents an average biogas production for the case of pure manure fermentation during a period when the anaerobic digestion process in digester was constant.

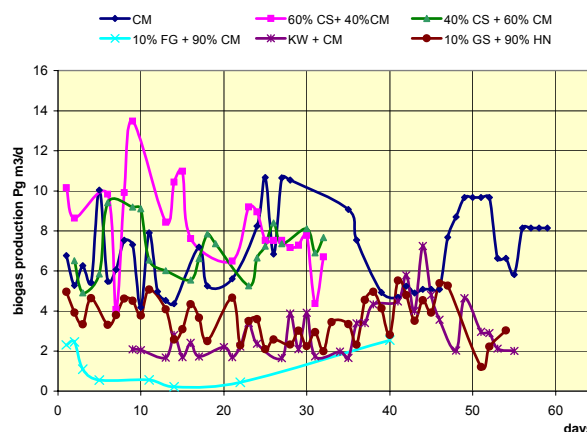


Fig. 5 Biogas production time behaviour

### CONCLUSION

The experiment results show that an average methane volume in the produced biogas did not change significantly in the particular cycles. In the case of co-fermentation of manure with grass silage or kitchen waste its slight increase can be observed. A similar experiment with co-fermentation of manure with kitchen waste was done in laboratory conditions at the Institute for biotechnology in Braunschweig where they added to the manure consequently 30, 50 and 70 % of waste. In their experiments due to the kitchen waste addition to the manure the methane volume was significantly increased by 17 %, and at an elongation of the substrate stay in digester to 65 days even by 50 % in comparison with the experiments with pure manure fermentation. In our experiments the kitchen waste addition led to an increase of the methane volume in the produced biogas but only less than 2 %.

A comparison of the average biogas production shows that the best results were achieved when corn silage was added to the manure for the co-fermentation. Adding 40 % of corn silage to the manure increased the average biogas production by 48,5 % and adding 60 % of corn silage to the manure resulted even in 72,7 % increase of the biogas production. In the other cases the average biogas production was decreased: the most remarkable decrease (by 73,5 %) was registered at co-fermentation manure with fresh grass.

## Forthcoming Events

### 8<sup>th</sup> International Stirling Forum, September 26 and 27, 2006, Osnabrueck

Especially in the fields of micro-cogeneration technology and biomass utilization the Stirling technology is gaining more and more attention worldwide. Therefore a larger number of user-friendly engines for generation of electricity and heat, coming from different parts of the world, will be introduced at the International Stirling Forum. Beside paper presentations and exhibits also demonstrations of marketable Stirling engines will round off the programme of the event.

The event will be held from **September 26 to September 27, 2006** in Osnabrueck, Germany, again in the very attractive seminar rooms of the Zentrum fuer Umweltkommunikation ZUK (Centre for Environmental Communication) of the Deutsche Bundesstiftung Umwelt DBU (German Environmental Foundation).

For additional information including the conference programme see the ISF 2006 homepage at:

[http://www.ecos-consult.com/energie/downloads/veranstaltungen/Stirling\\_Forum\\_GB.pdf](http://www.ecos-consult.com/energie/downloads/veranstaltungen/Stirling_Forum_GB.pdf)

Homepage of the International Stirling Forum: <http://www.ecos-consult.com/isf2006>

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If you are interested in being included on the MicroCHeaP mailing list then please email [robert@chalex.com](mailto:robert@chalex.com) or register your interest at [www.microcheap.org](http://www.microcheap.org)



### The 2<sup>nd</sup> MicroCHeaP Technology Transfer Workshop

March 2007  
Location: (TBA)

Details will be published on  
[www.microcheap.org](http://www.microcheap.org)  
when available

