# Project Order, Variations and Research Progress

## Project Title: Characterising the regional fluxes of methane seepage in the Surat Basin, Queensland

This document contains three sections. Click on the relevant section for more information.



GISERA, GPO Box 2583, Brisbane QLD 4001, Australia

# 1 Original Project Order

# Project Order

## Proforma 2012

### 1. Short Project Title (less than 15 words)

Methane seepage fluxes, Surat Basin, Queensland

| | |
|---|---|
| Long Project Title | Characterising the regional fluxes of methane seepage in the Surat Basin, Queensland |
| GISERA Project Number | Gas 1315 |
| Proposed Start Date | June 2013 |
| Proposed End Date | November 2017 |
| Project Leader | Stuart Day |

### 2. GISERA Research Program

- ☐ Biodiversity Research
- ☐ Marine Research
- ☐ Land Research
- ☐ Water Research
- ☐ Social & Economic Research
- ☒ GHG Research

## 3. Research Leader, Title and Organisation

Stuart Day
CSIRO Energy Flagship
Newcastle

## 4. Summary (less than 300 words)

This research proposal aims to address significant uncertainties associated with background seepage of methane and their detection and measurement in the Surat Basin, Queensland. By seepage we refer to the diffusive flux of methane to the atmosphere through the land surface and water bodies, the localised flux of methane *via* connectivity pathways consisting of leads, faults and outcrops and the flux from agricultural wells and bores. It does not consider the fugitive emissions of methane occurring as part of open cut and underground coal mines or emissions occurring from infrastructure (wells, compressors, associated water reticulation, or gas pipelines) associated with CSG production.

The research will provide:

(1) A desktop review and analysis of remote sensing imaging and direct detection (ground based flux) methods to quantify methane sources and fluxes;
(2) A field trial of methods at (a) a remote sensing pilot site, and (b) a ground based direct detection and monitoring pilot site. The remote sensing pilot will test the acceptable method(s) developed in Task 1 for deployment within a defined test area and ability to detect methane seeps more broadly in the Upper Condamine River catchment. The ground detection and monitoring pilot will test *in situ* measurement of on-ground methane fluxes at up to two pilot sites. Isotopic chemical tracers will assist in distinguishing coal methane seeps from biogenic methane sources. Each pilot is contingent on results from Task 1 and the client's input at decision points in the project; and,
(3) broad scale application of methods to a larger region in the Upper Condamine River catchment. This research will provide baseline monitoring data of methane seepage fluxes over different seasons. The final design is contingent on results from Tasks 1 and 2, their successful application and the client's input at decision points.

## 4b. Summary (variation – Methane emissions enhanced modelling

The atmospheric "top-down" approach provides continuous and independent monitoring of emissions. The atmospheric measurements and modelling in GISERA has been spread across a 3 year period to obtain a baseline on sources at the regional scale using fixed monitoring stations. The atmospheric monitoring, originally proposed to be one baseline station, will be enhanced to a network of 2 CSIRO stations and at least one industry station, all linked to the same concentration scales. This network will continuously monitor small differences in methane concentrations across the main CSG production area of the Surat Basin which will

be interpreted by atmospheric modelling to infer the locations and fluxes of the main gas sources, with defined uncertainties. In addition, measurements in the network of gases such as carbon dioxide and carbon monoxide (to help attribute emissions to sources including those unrelated to CSG such as combustion), and evidence of known methane sources coming from the ground surveys, will be included in the modelling and result in a greater level of detail and confidence about the methane budget, including fugitive emissions. New and existing "bottom-up" information on point sources from inventories and from infrastructure based monitoring will be included as it comes to hand. These data may be provided from industry and other sources but specific emission data will also be provided throughout the project by targeted ground surveys, which were used successfully during Phase 2. A modelling framework will be developed to derive the main source areas and emissions using forward simulations and inverse methods. Improved confidence in the emissions estimates will be obtained by combining results from the top-down and bottom-up approaches.

This approach of combining world's best science in measurements and modelling will lead to a workable system with broad application to monitoring regional gas emissions.

The following table provides a summary of the aims, methods, outputs and outcomes of this project:

| Research Aim | Research Methods | Outputs | OUTCOMES |
|---|---|---|---|
| **Year 1** | | | |
| Task 1. A literature review of the science on all methods and technologies of $CH_4$ measurement in light of their applicability to quantifying fluxes and their variations at a range of spatial and temporal scales in the Surat Basin, Queensland. | Desktop study of scientific literature with, potentially, limited numerical modeling using synthetic or limited datasets to demonstrate feasibility of methods and their applicability to the measurement of diffuse $CH_4$ fluxes from a range of potential sources (including but not confined to terrestrial outcrops, preferential pathways, alluvium losses, river fluxes, biogenic sources, agricultural wells, and other infrastructure not part of CSG development fields). | A report advising on the scientific capabilities of all forms of $CH_4$ detection and measurement methodologies to be used in the Surat Basin to quantify fluxes and sources of background emissions. | A comprehensive assessment of the application of methods of $CH_4$ detection and measurement to an important sedimentary basin in which CSG development is underway. |
| Task 1.The development of agreed plans for a pilot program for measuring $CH_4$ fluxes on at least one study site. | Scoping of a pilot program of application of methods for CH4 flux measurement and its sources. | The report is to include a plan for deployment of these activities as part of a pilot study (Task 2) and year one of an ongoing baseline-monitoring program (Task 3). | A fully scoped plan for analysis of CH4 fluxes and sources for an important sedimentary basin in which CSG development is underway. |
| Task 2. Based on successful development of a plan pilot program, deploy appropriate technology for the measurement and sourcing of $CH_4$ from sources in the Surat Basin. | Deploy $CH_4$ measurement technologies as agreed in Task 1 (including, but not limited to, FTIR spectroscopy, laser, atmospheric concentration measurement, inverse atmospheric transport modeling, eddy covariance measurement, Flux chamber measurement, hyperspectral imaging, and/or isotope sampling) at pilot test site(s). Establish value of applied methodologies and identify | A report on the application of specified $CH_4$ methods at the pilot test site(s), the value of measurements and analysis and recommendations for development of the pilot test into a baseline-monitoring program. | A scientifically defensible pilot program to demonstrate the value of application of $CH_4$ measurement methodologies in the Surat Basin for the purpose of developing a long term monitoring program as CSG development occurs. |

| | | | |
|---|---|---|---|
| | uncertainties/gaps in their application. Scope plan for deployment of methods for one year to establish baseline monitoring | | |
| **Year 2** | | | |
| Task 3. Based on successful demonstration of value of the pilot program, deploy appropriate technology for $CH_4$ measurement and sourcing for the purpose of initiating a baseline monitoring study. | Application of the demonstrated methods to long term monitoring conditions. Analysis of the variation in CH4 fluxes from various sources in time and space. Analysis of the attribution of sources of CH4 fluxes to biogenic/thermogenic origins. An assessment of the value of baseline monitoring of background $CH_4$ fluxes. | A report on the long-term application of specified technologies for measurement of $CH_4$ fluxes and their sources in the Surat basin, Queensland, including an assessment of the degree of variation in fluxes on a range of space and time scales and specifications for ongoing operation of a baseline monitoring program. | The foundation of a baseline monitoring program, its methods and quantified uncertainties that will underpin an ongoing, long term monitoring program for the Surat Basin. |

## 5. Budget Summary

| Expenditure | 2011/12 Year 1 | 2012/13 Year 2 | 2013/14 Year 3 | 2014/15 Year 4 | 2015/16 Year 5 | Total |
|---|---|---|---|---|---|---|
| Labour | | | 471,837 | 822,706 | | 1,294,543 |
| Operating | | | 267,000 | 123,000 | | 390,000 |
| **Total Costs** | | | | | | |
| CSIRO | | | 738,837 | 945,705 | | 1,684,543 |
| **Total Expenditure** | | | **738,837** | **945,706** | | **1,684,543** |

| Expenditure per Task | 2011/12 Year 1 | 2012/13 Year 2 | 2013/14 Year 3 | 2014/15 Year 4 | 2015/16 Year 5 | Total |
|---|---|---|---|---|---|---|
| Task 1 | | | 111,553 | | | |
| Task 2 | | | 627,284 | | | |
| Task 3 | | | | 945,706 | | |
| Task 4 | | | | | | |
| Task 5 | | | | | | |
| **Total Expenditure** | | | **738,837** | **945,706** | | **1,684,542** |

| Cash Funds to Project Partners | 2011/12 Year 1 | 2012/13 Year 2 | 2013/14 Year 3 | 2014/15 Year 4 | 2015/16 Year 5 | Total |
|---|---|---|---|---|---|---|
| CSIRO | | | 537,755 | 583,952 | | 1,121,707 |
| **Total Cash to Partners** | | | 537,755 | 583,952 | | 1,121,707 |

| Source of Cash Contributions | 2011/12 Year 1 | 2012/13 Year 2 | 2013/14 Year 3 | 2014/15 Year 4 | 2015/16 Year 5 | Total |
|---|---|---|---|---|---|---|
| Australia Pacific LNG (on behalf of APPEA) | | | 537,755 | 583,952 | | 1,121,707 |
| **Total Cash Contributions** | | | **537,755** | **583,952** | | **1,121,707** |

| In-Kind Contribution from Partners | 2011/12 Year 1 | 2012/13 Year 2 | 2013/14 Year 3 | 2014/15 Year 4 | 2015/16 Year 5 | Total |
|---|---|---|---|---|---|---|
| CSIRO | | | 201,082 | 361,753 | | 562,835 |
| **Total In-Kind Contribution from Partners** | | | **201,082** | **361,753** | | **562,835** |

| | Total funding over all years | Percentage of Total Budget |
|---|---|---|
| Australia Pacific LNG (on behalf of APPEA) investment | $1,121,707 | 66.6% |
| CSIRO Investment | $562,835 | 33.4% |
| Total Other Investment | | |
| **TOTAL** | **$1,684,542** | **100%** |

## 5b. Budget Summary (variation – Methane emissions enhanced modeling)

| Expenditure | 2011/12 Year 1 | 2012/13 Year 2 | 2013/14 Year 3 | 2014/15 Year 4 | 2015/16 Year 5 | 2016/17 Year 6 | 2017/18 Year 7 | Total |
|---|---|---|---|---|---|---|---|---|
| Labour | | | | | 85,451 | 171,641 | 54,301 | 311,394 |
| Operating | | | | | 10,000 | 10,000 | - | 20,000 |
| **Total Costs** | | | | | **95,451** | **181,641** | **54,301** | **331,394** |
| CSIRO | | | | | 95,451 | 181,641 | 54,301 | 331,394 |
| **Total Expenditure** | | | | | **95,451** | **181,641** | **54,301** | **331,394** |

| Expenditure per Task | 2011/12 Year 1 | 2012/13 Year 2 | 2013/14 Year 3 | 2014/15 Year 4 | 2015/16 Year 5 | 2016/17 Year 6 | 2017/18 Year 7 | Total |
|---|---|---|---|---|---|---|---|---|
| Task 1 | | | | | 95,451 | 181,641 | 54,301 | 331,394 |
| Task 2 | | | | | | | | |
| Task 3 | | | | | | | | |
| Task 4 | | | | | | | | |
| Task 5 | | | | | | | | |
| **Total Expenditure** | | | | | **95,451** | **181,641** | **54,301** | **331,394** |

| Cash Funds to Project<br>Partners | 2011/12 Year 1 | 2012/13 Year 2 | 2013/14 Year 3 | 2014/15 Year 4 | 2015/16 Year 5 | 2016/17 Year 6 | 2017/18 Year 7 | Total |
|---|---|---|---|---|---|---|---|---|
| CSIRO | | | | | 70,000 | 140,000 | | 210,000 |
| Sub Total | | | | | 70,000 | 140,000 | | 210,000 |
| **Total Cash to Partners** | | | | | **70,000** | **140,000** | | **210,000** |

| Source of Cash Contributions | 2011/12 Year 1 | 2012/13 Year 2 | 2013/14 Year 3 | 2014/15 Year 4 | 2015/16 Year 5 | 2016/17 Year 6 | 2017/18 Year 7 | Total |
|---|---|---|---|---|---|---|---|---|
| GISERA | | | | | 70,000 | 140,000 | | 210,000 |
| **Total Cash Contributions** | | | | | **70,000** | **140,000** | | **210,000** |

| In-Kind Contribution from Partners | 2011/12 Year 1 | 2012/13 Year 2 | 2013/14 Year 3 | 2014/15 Year 4 | 2015/16 Year 5 | 2016/17 Year 6 | 2017/18 Year 7 | Total |
|---|---|---|---|---|---|---|---|---|
| CSIRO | | | | | 95,451 | 111,641 | -85,699 | 121,394 |
| **Total In-Kind Contribution from Partners** | | | | | | | | |

| | Total funding over all years | Percentage of Total Budget |
|---|---|---|
| GISERA Investment | 210,000 | 63% |
| CSIRO Investment | 121,394 | 37% |
| Total Other Investment | | |
| **TOTAL** | 331,394 | |

| Task | Milestone Number | Milestone Description | Funded by | Participant Recipient | Start Date (mm-yy) | Delivery Date (mm-yy) | Fiscal Year | Fiscal Quarter | Payment $ |
|---|---|---|---|---|---|---|---|---|---|
| **Task 1** | 1.1 | Report on review and analysis of literature on detecting and measuring diffuse sources of methane seeps and proposal for discrete testing at pilot sites in Task 2 | GISERA | CSIRO | 1.07.2013 | 31.08.2013 | 13/14 | 1 | $74,937 |
| **Task 2** | 2.1 | Remote sensing pilot studyf | GISERA | CSIRO | 1.09.2013 | 08.09.2014 | 14/15 | 2 | $81,701 |
| **Task 2** | 2.2 | Ground detection pilot study | GISERA | CSIRO | 1.10.2013 | 30.11.2014 | 14/15 | 2 | $399,116 |
| **Task 3** | 3.1 | • The continuous monitoring results – installation, commissioning and operation of the two field stations.<br>• Preliminary data available. | GISERA | CSIRO | 1.07.2014 | 30.11.2015 | 15/16 | 2 | 188,651 |
| **Task 3** | 3.2 | • Modelled development and analysis of continuous data.<br>• Periodic monitoring and field validation<br>• Trial of remote sensing technologies. | GISERA | CSIRO | 1.12.2015 | 30.11.2016 | 16/17 | 2 | 188,651 |
| **Task 3** | 3.3 | • Delivery of final report for Remote sensing baseline study and Ground detection baseline study | GISERA | CSIRO | 1.12.2016 | 30.11.2017 | 17/18 | 2 | 188,651 |
| **Task 4** | 4.1 | Prepare new data from new and emerging monitoring stations including Hopelands (Origin), from field surveys including EC fluxes, and of gas tracers. | GISERA | CSIRO | 30.11.2015 | 30.11.2016 | | | 35,000 |
| | 4.2 | Evaluate data from 4.1 for ability to determine the local and | GISERA | CSIRO | 30.11.2015 | 30.11.2016 | | | 35,000 |

| Task | Milestone Number | Milestone Description | Funded by | Participant Recipient | Start Date (mm-yy) | Delivery Date (mm-yy) | Fiscal Year | Fiscal Quarter | Payment $ |
|---|---|---|---|---|---|---|---|---|---|
| | | regional sources of methane. Screen data for non-CSG sources such as livestock and combustion emissions. | | | | | | | |
| | 4.3 | Use the selected data in forward modelling and improved inverse modelling to better constrain local and regional methane sources. | GISERA | CSIRO | 1.7.2016 | 1.8.2017 | | | 105,000 |
| | 4.4 | Report on results of enhanced modelling of additional data and the inferred emissions (can be combined with final report, Task 3.3). | GISERA | CSIRO | 1.12.2016 | 30.11.2017 | | | 35,000 |

## 6. Other Researchers

| Researcher | Time Commitment (project as a whole) | Principle area of expertise | Years of experience | Organisation |
|---|---|---|---|---|
| Damian Barrett | 0.05 | Environmental science and resources sector | >20 | CSIRO |
| Stuart Day | 0.30 | Methane sensing and detection | 25 | CSIRO |
| David Etheridge | 0.50 | Atmospheric trace gas composition and fluxes | 20 | CSIRO |
| Brad Sherman | 0.20 | Methane flux measurement in aquatic environments | >12 | CSIRO |
| Ashok Luhar | 0.40 | Atmospheric transport modelling | 20 | CSIRO |
| Zoe Loh | 0.40 | Concentration measurements and interpretation | 5 | CSIRO |
| Colin Allison | 0.35 | Isotopes and tracers | 20 | CSIRO |
| Cindy Ong | 0.30 | Remote sensing | >20 | CSIRO |
| Andrew Roger | 0.10 | Remote sensing | 11 | |
| Mark Dell 'Amico | 0.25 | Methane sensing and detection | 25 | CSIRO |
| Robyn Fry | 0.1 | Methane emissions | 10 | CSIRO |
| Steve Zegelin | 0.30 | High level skills in flux tower deployment and operation, and related soil and atmospheric measurements | >30 | CSIRO |
| Eva van Gorsel | 0.25 | Micrometeorology and fluxes | 15 | CSIRO |
| Technical Assistant | 0.80 | Remote atmospheric monitoring, calibrations, data management | 5-20 | CSIRO |

## 6b. Other Researchers (variation 2 – Methane emissions enhanced modelling)

| Researcher | Time Commitment (project as a whole) | Principle area of expertise | Years of experience | Organisation |
|---|---|---|---|---|
| David Etheridge | 0.18 | Atmospheric trace gas composition and fluxes | 20 | CSIRO O and A |
| Zoe Loh | 0.12 | Atmospheric measurements, calibration, data handling | 10 | CSIRO O and A |
| Ashok Luhar | 0.20 | Inverse modelling | 20 | CSIRO O and A |

| | | | | |
|---|---|---|---|---|
| Mark Hibberd | 0.13 | Forward modelling | 25 | CSIRO O and A |
| Darren Spencer | 0.10 | Instrumentation | 10 | CSIRO O and A |
| Paul Marvig | 0.10 | Field measurements | 30 | CSIRO Energy |
| Stephen White | 0.20 | Atmospheric chemistry | 10 | CSIRO Energy |

## 7. GISERA Objectives Addressed

This research will determine the flux and sources of background seeps of methane to the atmosphere which is an important determinant of the GHG footprint and a baseline for estimation of fugitive emissions from industry

## 8. Program Outcomes Achieved

See section 13

## 9. Program Outputs Achieved

Details are provided in *Section 15. Project Objectives and Outputs*

## 10. What is the knowledge gap that these research outputs will address?

There is currently no information on the size and source of background methane seepage to the atmosphere from the Surat Basin. This project will provide important baseline information on the characteristics and magnitude of methane seepage.

## 10b. What is the knowledge gap that these research outputs will address? (variation – Methane emissions enhanced modelling)

Measurement of surface to atmosphere fluxes is an accurate way of quantifying emissions of gases from a wide range of sources. Fluxes on the scale of 1 metre can be directly measured by chamber techniques and from to 100-1000 metres can be inferred from concentrations combined with modelling of individual source plumes. However, the limited scale and discontinuous nature of these techniques means that sources can be missed or their emissions incorrectly estimated, especially for sources which are distributed or diffuse and sporadic in time such as those likely to exist in the Surat Basin.

Broad scale atmospheric techniques on the other hand are continuous in time and can infer emissions across a large area from concentrations and atmospheric transport modelling. The limitation of this “top-down” approach is that multiple sources can be merged unless additional information is available.

This project will enhance the capability of GISERA baseline atmospheric monitoring by introducing into models additional data that is becoming available, such as

-new measurement stations (Hopelands, Origin) that can improve the spatial resolution of the model-inferred sources

-new tracers that can potentially discriminate methane from non-CSG sources such as livestock, vehicles and power stations

-a greater array of point or small scale source information from field surveys and infrastructure monitoring.

## 11. How will these Research outputs and outcomes be used in State Government and other water managers to achieve Adaptive Management of Water Resources?

The outputs of this project form the basis of a further project on estimation of methane fugitive emissions by coal seam gas development in the Surat Basin, Queensland.

## 12. Project Development

The Jurassic and Permian coal beds of eastern Australia have become an increasingly significant source of Australian gas production. Geochemical and isotope data indicate that the considerable stores of methane in these shallow coal seams are the result of $CO_2$-reduction methanogenesis from microbial activity occurring since uplift of eastern Australian geologic basins during the late Cretaceous and Tertiary (Faiz and Hendry 2006). The known 2P gas reserves in these seams amount to over 35,000 PJ, of which ~92% occur in the Surat and Bowen Basins (Kaye et al 2012).

Methane is a powerful 'greenhouse' gas contributing more than 20 times the global warming potential of $CO_2$ on a per mass basis. It is the most abundant organic compound in the earth's atmosphere. The total annual source of methane to the atmosphere is estimated to be about 580 Tg/year (Denman et al, 2007) largely from wetlands, lakes, rice cropping and ruminant animal production, biomass burning, landfill, and waste with about 6% from coal mining activities. Natural geological sources may account for about 10% of the total methane source (Lassey et al., 2007; Etiope et al., 2008).

Important geological sources of methane enter the atmosphere through natural seeps and fissures occurring in terrestrial and marine settings. The potential natural sources of methane to the atmosphere from sedimentary basins include surface exposed outcrops of shale and near-surface coal and *via* connectivity pathways along faults, cleavages, and alluvial sediments associated with rivers. 'Background' methane fluxes (i.e. those not associated with the CSG production) occur through biogenic processes in wetlands, swamps, rivers, and dams. In some locations, further background sources of methane are agricultural bores, feed lots, old exploration wells, landfill, wastewater and biomass burning. Fluxes from all of these sources are often episodic, ephemeral and difficult to observe.

It is possible that, in the Surat Basin, Queensland, all of these sources of methane to the atmosphere exist and it is important to be able to distinguish among them to determine those potentially susceptible to CSG production. Baseline data on the fluxes, sources, pathways and variations in natural methane seeps is required to separate 'background' or 'baseline' emissions from other human induced variation in methane emissions particularly in gas production regions such as the Surat Basin. Any perceived variation in methane production from seeps in this region are potential conflict points with communities and hence risks to the gas sector's production if there is a perception, even incorrectly, that the industry is responsible for this variation.

This project will address pathways of methane emissions that are considered 'non-anthropogenic'; that is, natural connectivity between coal seams and coal bearing aquifers and the atmosphere as a result of links occurring between these sources and the surface and will separate these sources of methane from biogenic sources such as decomposition of organic matter and feed lots. It will also consider methane emissions from agricultural wells. Consideration of the impacts of CSG field development on potential connectivity and preferred pathways of methane to the atmosphere will be part of future studies and their mitigation and are not considered in this study. Detection and quantification of fugitive emissions from CSG production will be part of another study to be undertaken by CSIRO (Day et al 2012).

Currently, there is virtually no information on baseline methane seeps in the Surat and no existing study has examined the impacts of coal seam gas development on these background fluxes of methane. Nor have these studies investigated potential impacts of gas field development (both positive and negative) on these fluxes.
This project aims to generate for the first time a comprehensive quantitative estimate of baseline methane emissions from soils, rivers and agricultural infrastructure at a regional scale in the Surat Basin. The project is designed in Tasks that increment knowledge toward this aim. Both the client and research agency have input into decisions during the project on the emphasis and timing of Tasks. The approach is to examine a range of methods and their applications in a phased manner. At the conclusion of the two years, the result will be a comprehensive study of the location and flux of methane seeps (terrestrial and aquatic), the governing processes and sources of methane and the establishment of a baseline against which ongoing monitoring can occur.

## 12b. Project Development (variation – Methane emissions enhanced modelling)

This project builds on the atmospheric monitoring for a methane emission baseline of the Surat Basin region to provide more definitive results on methane sources and their emissions.
GISERA Phase 2 incorporated prior estimates of methane emissions in the Surat Basin in modelling to predict the likely perturbations of atmospheric concentrations for present emissions estimates and for a growth scenario. Two stations have recently been installed in optimum locations to monitor these possible baseline signals.
The enhancement proposed here brings in new information that is becoming available since the Phase 2 concept. In addition to the baseline concentrations, ground survey concentration and flux data from Task 3, the enhanced project will include new station monitoring data (greenhouse gases and tracers from ground based stations including new air quality stations such as Hopelands, Origin)and information from collaborators such as the University of Melbourne and industry based monitoring. The aim is to give more detailed and better resolved estimates of source area, type (large infrastructure sources such as gas processing plants and power stations, feedlots, coal mines, significant seeps) and emissions.

## 13. Project Objectives and Outputs

The three Tasks of this research program build a hierarchy of knowledge whereby later Tasks use information and understanding developed in the earlier Tasks to underpin further work.

The **first Task** consists of a survey, review and analysis of literature on methane detection and measurement. The literature will be assessed on its applicability to develop customised methods for application to the task of quantifying methane sources and fluxes from seeps in the Surat Basin. Utilising the collective, internationally recognised skills within CSIRO, methods for remote sensing imaging, spectroscopy, atmospheric concentration, flux and source detection will be reviewed and a best strategy based on these methods will be proposed for deployment in the Surat Basin in Tasks 2 and 3. Proposals for limited discrete testing of remote sensing and ground detection methods at pilot sites will be completed and evaluated by the client. From this, agreement will be reached on how to proceed with either a remote sensing pilot, a ground detection pilot or both in Task 2. The proposals will include a review of methods for monitoring fluxes to determine baseline sources and potential natural variation. A report will advise on the best methods for deployment of a pilot study flux and establishment of a broader scale application of methods.

The **second Task** will utilise the strategy from Task 1 to deploy a pilot study of methane sources in the Surat basin. The pilot study will be field trial(s) of (a) a remote sensing pilot, and/or (b) a ground based detection and monitoring pilot. The remote sensing approach will test laser and imaging methods. The ground based detection will test the use of atmospheric concentration and flux measurements as inputs to determine the capability of atmospheric transport modelling to determine fluxes of methane on a range of spatial scales. Limited ground based gas geochemistry sampling for isotopic analyses and dissolved methane concentrations will be used to determine whether pilot site methane losses are of biogenic or coal origin and potentially assist with locating the source of the methane.

Finally, the **third Task** will apply a broad scale application of methods to assess regional methane sources (based on Task 2 results) based on remote sensing methods. An option exists to apply these methods to develop a survey of regional methane sources within the Surat basin from which a register of methane sources would be developed for the Condamine. Ongoing ground based monitoring of pilot sites will provide a baseline of methane seepage fluxes and their seasonal variations as the basis of an ongoing monitoring program.

## 13b. Project Objectives and Outputs (variation – Methane emissions enhanced modelling)

- Analyse and prepare additional data from new and emerging monitoring stations in a network across the Surat Basin for a more definitive source estimation.

- Quantify contributions from sources through forward modelling using existing and new information on inventories and that from infrastructure based monitoring.
- Develop an inverse modelling framework to better constrain the main source areas and emissions using data from the new and emerging monitoring stations and information from forward modelling.

Outputs include:

- A modelling methodology to better estimate sources using data from a variety of measurement systems.
- Report and a journal publication describing the methodology and results

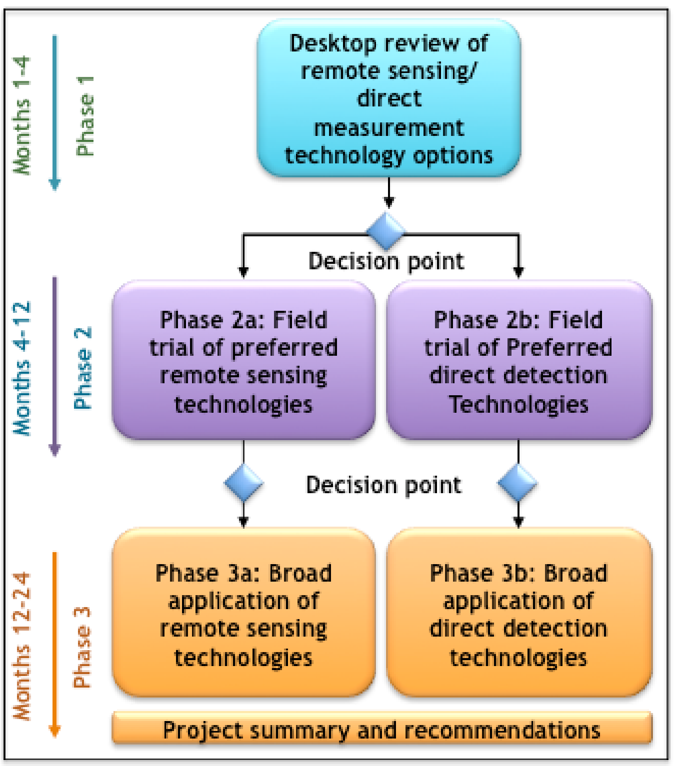
## 14. Project Plan

The program of work applies existing CSIRO capability to review methods and develop an integrated measurement program of methane sources and fluxes. CSIRO already has expertise in this domain through a well established program of work on coal seam methane fugitive emissions for the coal mining industry and more recently work on fugitives related to coal seam gas production.

The proposed work involves a comprehensive analysis of methane sensing and measurement methods followed by implementation of measurement activities at pilot sites and extensive deployment within the Surat Basin.

The **aim** of this research program is:

***To refine methods of methane detection, locate existing significant seeps, identify sources of methane, characterize the flux of gas and develop a scientifically robust baseline of methane fluxes from seeps.***




The challenge is to identify methane that has migrated from a coal seam reservoir to the surface *via* seepage and separate these fluxes from other sources (e.g. biogenic methane). The research is designed to proceed in three Tasks with decision points separating each Task. The decision point is designed to ensure shared negotiation/decision making occurs between the Research Advisory Committee, APLNG and CSIRO prior to embarking on Tasks 2 and 3 in order to ensure deliverables are aligned with the best deployment of methods. The decision points also take into account the exploratory nature of the research in recognition of the significant uncertainties surrounding background methane seepage in the Surat Basin. It is possible that parts of Tasks 2 and 3 could be undertaken in a parallel fashion based on mutual agreement between APLNG and CSIRO.

### 14.1 Project Schedule

| ID | Task Title | Task Leader | Scheduled Start | Scheduled Finish | Predecessor |
|---|---|---|---|---|---|
| **Task 1** | Review & analysis of literature | Stuart Day | 1 July 2013 | 31 August 2013 | |
| **Task 2.1** | Remote sensing pilot study | Stuart Day | 1 October 2013 | 8 Sep 2014 | |
| **Task 2.2** | Ground detection pilot study | Stuart Day | 1 July 2014 | 28 Feb 2015 | |
| **Task 3.1** | · The continuous monitoring results – installation, commissioning and operation of the two field stations.<br>· Preliminary data available. | Stuart Day | 1 July 2014 | 30 Nov 2015 | |
| **Task 3.2** | □Modelled development and analysis of continuous data.<br>□Periodic monitoring and field validation<br>□Trial of remote sensing technologies. | Stuart Day | 1 Dec 2015 | 30 Nov 2016 | |
| **Task 3.3** | □Delivery of final report for Remote sensing baseline study and Ground detection baseline study | Stuart Day | 1 Dec 2016 | 30 Nov 2017 | |
| **Task 4.1** | New data prepared | David Etheridge | 30.11.2015 | 30-11-2016 | |

| | | | | | |
|---|---|---|---|---|---|
| **Task 4.2** | Data screened, assessed | David Etheridge | 30.11.2015 | 30-11-2016 | |
| **Task 4.3** | Models developed and applied to new data | Ashok Luhar | 1.7.2016 | 1-8-2017 | |
| **Task 4.4** | Report prepared | David Etheridge | 1.12.2016 | 30-11-2017 | |

**Task 1**

**TASK NAME:** Survey, review and analysis of literature

**TASK LEADER:** Stuart Day

**OVERALL TIMEFRAME:** It is proposed to finish Task 1 in 4 months.

**BACKGROUND:** xx. The first Task consists of a literature review and analysis of methane detection and measurement methods with the aim of tailoring a set of methods to the specific problem of locating and quantifying methane seeps in the Surat Basin. The review will also consider the sensitivity of methods to the task of detecting and quantifying fluxes. This Task will reduce the very significant uncertainties associated with this problem and provide a sound basis for Tasks 2 and 3. The review will include two components: (a) remote sensing methods (FTIR and laser spectroscopy and hyperspectral imaging/spectroscopy methods) and (b) direct ground based detection (mobile Piccaro CRDS analyser + GPS). The most suitable approach will depend on the type of sources (terrestrial or aquatic), the flux and area of seepage and the resulting atmospheric concentrations (under differing meteorological conditions). Existing remote measurement methods for methane detection work well for concentrated point sources (e.g. pipeline leaks) but function poorly when used to detect and measure diffuse low concentration fluxes such as seeps. The research task being tackled in this project is to design, tailor, develop and adapt methods to this problem.

**TASK OBJECTIVE**: Review and analyse literature on methane detection and measurement. Development of tailored methods for application at pilot sites in the Surat Basin, Queensland.
**TASK OUTPUTS & SPECIFIC DELIVERABLES**: The output from Task 1 will be a report containing proposals for discrete testing of methods at pilot sites for use in Task 2 and the design of measurement protocols to quantify the variability in baseline sources and ongoing monitoring at monitoring sites.

**PROGRESS REPORT**: The final draft report was submitted to APPEA on 18 December 2013. The literature review has gone through the mandatory internal review process and is now publicly available on the GISERA website http://www.gisera.org.au/publications/tech_reports_papers/ghg-emission-proj-1-lit-review.pdf.

**Task 2.1**

**TASK NAME:** Remote Sensing method pilot study

**TASK LEADER:** Stuart Day

**OVERALL TIMEFRAME:** It is proposed that Task 2 be undertaken over 8 months and be finished at 12 months.

**BACKGROUND:** Task 2 consists of utilising knowledge gained in Task 1 to deploy methods at pilot test sites. Prior to deployment at pilot sites, model testing is required to ensure the best application of methods. Due to the highly uncertain nature of methane seeps in this region, a significant amount of interpretation and testing of numerical models will be required as part of the review process. It is important that characterization of the drivers of methane fluxes and their response processes can be understood and interpreted by source modelling. The review of methods will consider the measurements and numerical modelling requirements for work undertaken at three scales or 'footprints' of methane loss to the atmosphere:

1) Localised (1 – 10 m) flux chamber measurements and interpretation of methane sources
2) Landscape (100 – 1000 m) eddy covariance measurements from which methane fluxes are determined
3) Regional (100 – 10,000 m) inverse derivation of methane fluxes using atmospheric transport modeling methods based on the observed concentrations.

The pilot studies will be applied to methane sources using a combination of methods identified, developed, tested and refined in Task 1 and model testing in Task 2. Ground based methods potentially include atmospheric concentration measurements with accompanying meteorology and chamber measurements to both calculate fluxes and obtain samples for pilot isotopic analyses.

**TASK OBJECTIVE:** The remote sensing pilot will examine Fourier Transform Infrared (FTIR) spectroscopy, Laser spectroscopy and hyperspectral imaging/spectroscopy methods to determine suitability for ground based or airborne measurements of seeps. A range of new, cheaper sensors are appearing on the market and these will be evaluated along with existing methods to determine best approach for this application. This will require resolving a suite of technical difficulties and questions associated with each method and testing them against diffuse, low concentration sources of methane in the atmosphere.

**TASK OUTPUTS & SPECIFIC DELIVERABLES:** Report on application of methods at pilot sites and recommendations for establishing baseline measurements

**PROGRESS REPORT:** The interim report for Phase 2 (which only relates to the remote sensing component) has been through the mandatory internal review and was submitted to Rick Wilkinson at APPEA on 11 November 2014.

**Task 2.2**

**TASK NAME:** Ground detection pilot study

**TASK LEADER:** Stuart Day

**OVERALL TIMEFRAME:** It is proposed that Task 2 be undertaken over 8 months and be finished at 12 months.

**BACKGROUND:** Task 2 consists of utilising knowledge gained in Task 1 to deploy methods at pilot test sites. Prior to deployment at pilot sites, model testing is required to ensure the best application of methods. Due to the highly uncertain nature of methane seeps in this region, a significant amount of interpretation and testing of numerical models will be required as part of the review process. It is important that characterization of the drivers of methane fluxes and their response processes can be understood and interpreted by source modelling. The review of methods will consider the measurements and numerical modelling requirements for work undertaken at three scales or 'footprints' of methane loss to the atmosphere:

1) Localised (1 – 10 m) flux chamber measurements and interpretation of methane sources
2) Landscape (100 – 1000 m) eddy covariance measurements from which methane fluxes are determined
3) Regional (100 – 10,000 m) inverse derivation of methane fluxes using atmospheric transport modeling methods based on the observed concentrations.

The pilot studies will be applied to methane sources using a combination of methods identified, developed, tested and refined in Task 1 and model testing in Task 2. Ground based methods potentially include atmospheric concentration measurements with accompanying meteorology and chamber measurements to both calculate fluxes and obtain samples for pilot isotopic analyses.

**TASK OBJECTIVE:** The on-ground pilot will utilise observations of atmospheric methane concentration as data constraints in models to determine fluxes from locations and their potential variation in response to known drivers. Inverse methods will be trialled at these pilot sites to obtain best estimates of source fluxes of methane and their variability. Inverse modelling is the most scientifically rigorous approach to examining the mechanisms driving variation in background methane fluxes. The modelling undertaken will form the bases for a scientifically robust interpretation of measurements and longer application of methods in Task 3 to establish baseline fluxes and their variations.

If the pilot site consists of methane fluxes from water bodies, the work will build on existing research undertaken in CSIRO in the Condamine River. Methane fluxes from aquatic systems with free water surfaces (e.g. river weir pools, farm dams) will be quantified using floating chambers used in one of two modes:

1) For low fluxes typical of natural waters the head-space gas is recirculated through a high precision gas analyser (Picarro CRDS) following the protocols used by CSIRO for similar research in water supply reservoirs;
2) For high fluxes (i.e. vigorous bubbling), a once-through system currently being developed and trialled by CSIRO will be employed in which gas captured by a chamber is diluted by ambient air drawn through the chamber and subsequently analysed using a high precision gas analyser.

Initial sampling is to be conducted at a coarse spatial resolution to identify important spatial gradients in fluxes. Subsequent sampling will be undertaken at higher spatial resolution to reduce uncertainty in the overall areal mean flux to within satisfactory levels. Adequate characterisation of instantaneous fluxes from a weir pool experiencing decomposition of catchment-supplied organic matter can be completed in 1-2 days of sampling (depending on spatial scale; 1 day of sampling should be sufficient for volumes < 2000 ML). Characterisation of seasonal variability requires 3 to 4 sampling experiments and would be undertaken in Task 3. Interannual variability is likely to be very high in systems subject to flooding on an irregular basis as flood waters will supply large amounts of organic matter that will degrade rapidly over the first year but may continue to fuel methanogenesis at a lower rate for several years. Characterising interannual variability would require ongoing monitoring following Task 3.

At the pilot sites, flux chamber measurements, combined with **limited** isotopic analyses will be used to differentiate reservoir methane from other potential sources. Once started the isotope observations will enable planning for potentially more detailed sampling based on cost and importance (in Task 3). More extensive sampling and detailed work is planned in Task 3 depending on results from the pilot sites. Terrestrial sites may include soil-air space sampling and soil water sampling. Aquatic sites will include chamber measurements of fluxes, samples of bubble methane and associated samples of river water to measure dissolved methane concentrations. The geochemistry of these samples will assist with establishing sources of methane and flux measurements will determine quantities of methane generated per unit time.

Measurements of samples will consist of limited isotopic composition (such as $^{13}CH_4$, $CH_3D$, $^{14}CH_4$), $CH_4$ concentration in air, soils, water and direct from source, and a suite of geochemical elements as potential tracers to identify sources.

In aquatic sites, we will also conduct the following sampling and measurements:

- Collect and analyze (by ICPMS) water samples for basic geochemical constituents to characterize possible groundwater exchanges with the river.
- Collect and analyze water samples for 13C isotopes, alkalinity and TIC.
- Collect gas samples and analyze for composition ($C_1$-$C_5$, $O_2$+Ar, $N_2$, $CO_2$, $d^{13}C$ - $CH_4$, $d^2D$ - $CH_4$)

Collect and analyze water samples to characterize the spatial variability of dissolved methane and compute any associated fluxes.

**TASK OUTPUTS & SPECIFIC DELIVERABLES:** Report on application of methods at pilot sites and recommendations for establishing baseline measurements

**PROGRESS REPORT**: The final report for Phase 2 (which includes the remote sensing and ground detection components) has been through the compulsory internal review. It is available on the GISERA website for viewing GHG Emission_Methane seeps_stage 2 report

**Task 3**

**TASK NAME:** Broad scale application of methane detection

**TASK LEADER:** Stuart Day

**OVERALL TIMEFRAME:** It is proposed that Task 3 will be undertaken over 12 months and begun at the end of the first year to coincide with the culmination of the pilot remote sensing imaging of seeps.

**BACKGROUND:** The third Task will extend the tested remote sensing methods from Tasks 1 and 2 at a more broad scale in the Surat Basin (Upper Condamine River catchment) to assess regional methane sources and fluxes. Using the most suitable remote sensing methodology from Task 1 and 2, a survey to cover the Surat Basin will be undertaken to enable identification of the location of sources of methane. The survey method will need to be sufficiently wide and frequent to ensure that all material sources of methane are located and documented. If successful this approach would allow development of a register of methane sources. The register of significant methane sources provides further information for a baseline to establish ongoing monitoring or for more intensive examination of selected locations in the future. The approach and methods will be developed in consultation with industry representatives to ensure the measurement program compliments existing sampling already undertaken by industry and to meet industry needs.

**TASK OBJECTIVE:** The third Task will also extend monitoring at the aforementioned pilot sites in order to begin developing an ongoing set of baseline measurements used to determine day-to-day, season-to-season and year-to-year variation in methane fluxes. This activity will reduce the considerable uncertainties associated with background methane fluxes in the Surat Basin and contribute to the establishment of a sound baseline. This component extends and refines the direct concentration and flux measurement techniques developed and applied in Task 2.

**TASK OUTPUTS:** Report on development of baseline measurements and plan for ongoing monitoring

**SPECIFIC DELIVERABLES:** The scientific review in Task 1 will provide robust knowledge as to the best selection of detection and measurement methods for this particular region.

The data provided by this project will provide an important baseline data set that allows an objective, quantitative comparison of methane fluxes and concentrations to be undertaken in the future as CSG production in the Surat Basin accelerates.

Outcomes from this work to APLNG, the CSG sector and communities include a comprehensive and scientifically rigorous analysis of background methane fluxes and the establishment of a baseline for an important part of the Surat Basin, Queensland, in which CSG development is occurring and against which ongoing monitoring can conducted.

Through this program of research, a critical unknown in CSG production will be reduced thereby contributing to maintaining and improving environmental stewardship by the industry.

References used in Task section:

Day S, Connell L, Etheridge D, Norgate T and Sherwood N (2012) Fugitive greenhouse gas emissions from coal seam gas production in Australia. CSIRO Australia, 27 pp.

Denman, K. L., et al. (2007), Couplings between changes in the climate system and biogeochemistry, in Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, edited by S. Solomon et al., chap. 7, pp. 499 – 587, Cambridge Univ. Press, Cambridge, U.K.

Etiope, G., K. R. Lassey, R. W. Klusman, and E. Boschi, 2008: Reappraisal of the fossil methane budget and related emission from geologic sources. *Geophysical Research Letters 35: L09307.*, **35**, L09307.

Faiz M and Hendry P (2006) Significance of microbial activity in Australia coal bed methane reservoirs – A review. *Bulletin of Canadian Petroleum Geology*. 54, 261 – 272

Kaye L, Barrett DJ, Vink S, Roux E, Murray C-E, White J, Robbins S (2012) Coal Seam Gas, Coal and Agriculture: Water Implications. Report for ACARP Project C21006. *Australian Coal Association Research Program*. 139 pp.

Lassey, K. R., Etheridge, D. M., Lowe, D. C., Smith, A. M., Ferretti, D. F. Centennial evolution of the atmospheric methane budget: what do the carbon isotopes tell us?. Atmospheric chemistry and physics. 2007; 7:2119-2139.

**Task 4.1**

**TASK NAME:** Prepare new data

**TASK LEADER:** David Etheridge

**OVERALL TIMEFRAME:** 30.11.2015-30.11.2016

**BACKGROUND:** Data from Ironbark and Burncluith stations should be available and complemented by additional tracer gas measurements from the new industry air quality monitoring stations (including Origin's Hopelands). Field surveys will be undertaken and data made available.

**TASK OBJECTIVE:** Compile and calibrate new station concentration data to include with Ironbark and Burncluith. Compile emissions and flux information from field surveys (from Phase 2 and from new tasks) to inform modelling.

**TASK OUTPUTS & SPECIFIC DELIVERABLES:** Calibrated data sets of greenhouse gas concentrations and tracer gases across a network of stations in the Surat Basin. Data base of locations and emissions strengths of known sources to inform forward and inverse modelling.

**Task 4.2**

**TASK NAME:** Screen and evaluate data

**TASK LEADER:** David Etheridge

**OVERALL TIMEFRAME:** 30.11.2015-30.11.2016

**BACKGROUND:** Station data from Task 4.1 available.

**TASK OBJECTIVE:** To screen and filter data and develop techniques to identify confounding local sources such as livestock, vehicles, power plants and fires, using multiple species concentrations, tracer gases and information on wind trajectories, Identify the underlying main source signals in the screened data.

**TASK OUTPUTS & SPECIFIC DELIVERABLES:** Screened data sets from the ground based atmospheric monitoring network, which will then be used for modelling. Main source locations identified.

**Task 4.3**

**TASK NAME:** Develop and apply models

**TASK LEADER:** Ashok Luhar

**OVERALL TIMEFRAME:** 1.7.2016-1.8.2017

**BACKGROUND:** This task requires source locations and emissions strengths from field surveys; Screened and evaluated concentration data from Task 4.2; Meteorological and flux data from Ironbark and Burncluith stations and emerging industry stations (Origin's Hopelands).

**TASK OBJECTIVE:** Develop the modelling framework for the Surat Basin, using TAPM (CSIRO meteorological and dispersion model) in forward and inverse modes. Use predicted concentration fields from forward modelling simulations of prior source estimates from Phase 2 as initial conditions. Constrain atmospheric transport with meteorological and flux station data. Include known sources in the model and compare with observations over the GISERA monitoring period. Identify and estimate emissions from main source areas not previously known or identified in field surveys. Attribute source type using multiple gas species and follow up ground surveys.

**TASK OUTPUTS & SPECIFIC DELIVERABLES:** A modelling capability to infer methane sources across the Surat Basin with more definitive information on source locations and types than would be available from the baseline atmospheric monitoring and modelling in Phase 3. Reports, presentations and a draft journal publication on the technique and the findings.

**Task 4.4**

**TASK NAME:** Report on enhanced monitoring.

**TASK LEADER:** David Etheridge

**OVERALL TIMEFRAME:** 1.12.2016-30.11.2017

**BACKGROUND:** Successful progress on Tasks 4.1-4.4

**TASK OBJECTIVE:** To report on atmospheric concentration monitoring network, field surveys, modelling framework and inferred source information from enhanced monitoring and modelling program.

**TASK OUTPUTS & SPECIFIC DELIVERABLES:** Report on enhanced monitoring and modelling project to GISERA, possibly combined with final report (Task 3.3).

## 15. Budget Justification

The budget for this project has been agreed between APPEA, APLNG and CSIRO. APPEA identified the project as one of particular public and industry interest and has, on behalf of the industry and via APLNG, contributed whole-of-industry funds to the project. APPEA funds appear 'via APLNG' because APLNG is a member of GISERA, APPEA is not. The Research Advisory Committee and Management Committee have approved this budget.

## 16. Project Governance

The project leaders and APPEA/APLNG representatives will meet at least 1 month prior to delivery of milestone reports to discuss project management issues and no less than on six monthly intervals. There are three 'decisions points' in the project plan that enable input from industry representatives, the GISERA Research Advisory Committee and CSIRO researchers as to the specific direction of research work conducted in this project. Decisions will be made by mutual agreement between researchers and industry representatives, and will be offered for and will require ratification by the GISERA Research Advisory Committee.

## 17. Communications Plan

GISERA will manage communications in accordance with GISERA's Alliance Agreement (available at: http://www.gisera.org.au/contract.html) and Communications Strategy.

## 18. Risks

Capacity to deliver this project will be managed by CSIRO. Risks in delivery will be mitigated using the breadth of skills across the organisation. Communication risks will be mitigated by adherence to the communications protocols outlined in the GISERA Communications Strategy and the GISERA Alliance Agreement. CSIRO will undertake all project management tasks and will consult with APLNG on decisions points and contingencies in the work program.

# 2 Variations to Project Order

Changes to research Project Orders are approved by the GISERA Director, acting with authority provided by the GISERA National Research Management Committee, in accordance with the National GISERA Alliance Agreement.

The table below details variations to research Project Order.

### Register of changes to Research Project Order

| Date | Issue | Action | Authorisation |
|---|---|---|---|
| 07/05/14 | Finalising phase 2 work program was completed end of March 2014. | Milestone 2.1 will be pushed back to Sept 2014. | |
| 07/05/14 | Finalising phase 2 work program was completed end of March 2014. | Milestone 2.2 will be pushed back to Nov 14. | |
| 07/05/14 | Finalising phase 2 work program was completed end of March 2014. | Milestone 3.1 will be pushed back to Nov 2015. | |
| 07/05/14 | Finalising phase 2 work program was completed end of March 2014. | Milestone 3.2 will be pushed back to Nov 15. | |
| 18/12/14 | As a result of the decision to have phase 2 report reviewed externally, delivery date to be pushed back. | Milestone 2.2 will be pushed back to February 2015. | |
| 24/07/15 | Phase 3 will be extended over 3 years with annual reviews on progress. Will provide project with opportunity to establish a longer and more significant set of baseline measurements than originally planned. | Milestone 3.1 due in Nov 15, milestone 3.2 due in Nov 16 and milestone 3.3 will be due in Nov 17. | |

| Date | Issue | Action | Authorisation |
|---|---|---|---|
| 29/11/15 | Methane emissions enhanced modelling approved resulting in 4 additional milestones. | Milestone 4.1, 4.2, 4.3 and 4.4 now added to this project. | |
| 29/3/17 | Staff movements have resulted in delays in meeting deliverables. | Milestone 3.3 pushed back to 28 Feb 2018, milestone 4.3 pushed back to 30 Nov 2017 and milestone 4.4 pushed back to Feb 2018. | |

# 3 Progress against project milestones

Progress against milestones are approved by the GISERA Director, acting with authority provided by the GISERA National Research Management Committee, in accordance with the National GISERA Alliance Agreement.

Progress against project milestones/tasks is indicated by two methods: Traffic Light Reports and descriptive Project Schedule Reports.

1. Traffic light reports in the Project Schedule Table below show progress using a simple colour code:
   - Green:
     - Milestone fully met according to schedule.
     - Project is expected to continue to deliver according to plan.
     - Milestone payment is approved.
   - Amber:
     - Milestone largely met according to schedule.
     - Project has experienced delays or difficulties that will be overcome by next milestone, enabling project to return to delivery according to plan by next milestone.
     - Milestone payment approved for one amber light.
     - Milestone payment withheld for second of two successive amber lights; project review initiated and undertaken by GISERA Director.
   - Red:
     - Milestone not met according to schedule.
     - Problems in meeting milestone are likely to impact subsequent project delivery, such that revisions to project timing, scope or budget must be considered.
     - Milestone payment is withheld.
     - Project review initiated and undertaken by GISERA Research Advisory Committee.

2. Progress Schedule Reports outline task objectives and outputs and describe, in the 'progress report' section, the means and extent to which progress towards tasks has been made.

Gas Industry Social & Environmental Research Alliance

## Project Schedule Table

| ID | Task Title | Task Leader | Scheduled Start | Scheduled Finish | Predecessor |
|---|---|---|---|---|---|
| **Task 1** | Review & analysis of literature | Stuart Day | 1 July 2013 | 31 August 2013 | N/A |
| **Task 2.1** | Remote sensing pilot study | Stuart Day | 1 Sept 2013 | 8 Sept 2014 | Task 1 |
| **Task 2.2** | Ground detection pilot study | Stuart Day | 1 Oct 2013 | 28 Feb 15 | Task 2 |
| **Task 3.1** | • The continuous monitoring results – installation, commissioning and operation of the two field stations.<br>• Preliminary data available. | Stuart Day | Jul 2014 | Nov 15 | |
| **Task 3.2** | • Modelled development and analysis of continuous data.<br>• Periodic monitoring and field validation<br>• Trial of remote sensing technologies. | Stuart Day | 1 Dec 15 | Nov-16 | |
| **Task 3.3** | • Delivery of final report for Remote sensing baseline study and Ground detection baseline study | Stuart Day | 1 Dec 16 | Feb-18 | |
| **Task 4.1** | Prepare new data from new and emerging monitoring stations including Hopelands (Origin), from field surveys including EC fluxes, and of gas tracers. | David Etheridge | 30 Nov 15 | Nov-16 | |
| **Task 4.2** | Evaluate data from 4.1 for ability to determine the local and regional sources of methane. Screen data for non-CSG sources such as livestock and combustion emissions. | David Etheridge | 30 Nov 15 | Nov-16 | |

| ID | Task Title | Task Leader | Scheduled Start | Scheduled Finish | Predecessor |
|---|---|---|---|---|---|
| **Task 4.3** | Use the selected data in forward modelling and improved inverse modelling to better constrain local and regional methane sources. | David Etheridge | 1 Jul 16 | Nov-17 | |
| **Task 4.4** | Report on results of enhanced modelling of additional data and the inferred emissions (can be combined with final report, Task 3.3). | David Etheridge | 1 Dec 16 | Feb-18 | |

## Project Schedule Report

### Task 1

**TASK NAME: Survey, review and analysis of literature**

**TASK LEADER:** Stuart Day

**OVERALL TIMEFRAME:** 2013

**BACKGROUND:** The first Task consists of a literature review and analysis of methane detection and measurement methods with the aim of tailoring a set of methods to the specific problem of locating and quantifying methane seeps in the Surat Basin. The review will also consider the sensitivity of methods to the task of detecting and quantifying fluxes. This Task will reduce the very significant uncertainties associated with this problem and provide a sound basis for Tasks 2 and 3. The review will include two components: (a) remote sensing methods (FTIR and laser spectroscopy and hyperspectral imaging/spectroscopy methods) and (b) direct ground based detection (mobile Piccaro CRDS analyser + GPS). The most suitable approach will depend on the type of sources (terrestrial or aquatic), the flux and area of seepage and the resulting atmospheric concentrations (under differing meteorological conditions). Existing remote measurement methods for methane detection work well for concentrated point sources (e.g. pipeline leaks) but function poorly when used to detect and measure diffuse low concentration fluxes such as seeps. The research task being tackled in this project is to design, tailor, develop and adapt methods to this problem.

**TASK OBJECTIVE:** Review and analyse literature on methane detection and measurement. Development of tailored methods for application at pilot sites in the Surat Basin, Queensland.

**TASK OUTPUTS:** The output from Task 1 will be a report containing proposals for discrete testing of methods at pilot sites for use in Task 2 and the design of measurement protocols to quantify the variability in baseline sources and ongoing monitoring at monitoring sites.

### PROGRESS REPORT:

The final draft report was submitted to APPEA on 18 December 2013. The literature review has gone through the mandatory internal review process and is now publicly available on the GISERA website Characterisation of Regional Fluxes of Methane in the Surat Basin, Phase 1: A Review and Analysis of Literature on Methane Detection and Flux Determination.

### Task 2.1

**TASK NAME: Remote Sensing method pilot study**

**TASK LEADER:** Stuart Day

**OVERALL TIMEFRAME:** 2014

**BACKGROUND**: Task 2 consists of utilising knowledge gained in Task 1 to deploy methods at pilot test sites. Prior to deployment at pilot sites, model testing is required to ensure the best application of methods. Due to the highly uncertain nature of methane seeps in this region, a significant amount of interpretation and testing of numerical models will be required as part of the review process. It is important that characterization of the drivers of methane fluxes and their response processes can be understood and interpreted by source modelling. The review of methods will consider the measurements and numerical modelling requirements for work undertaken at three scales or 'footprints' of methane loss to the atmosphere:

1) Localised (1 – 10 m) flux chamber measurements and interpretation of methane sources
2) Landscape (100 – 1000 m) eddy covariance measurements from which methane fluxes are determined
3) Regional (100 – 10,000 m) inverse derivation of methane fluxes using atmospheric transport modeling methods based on the observed concentrations.

The pilot studies will be applied to methane sources using a combination of methods identified, developed, tested and refined in Task 1 and model testing in Task 2. Ground based methods potentially include atmospheric concentration measurements with accompanying meteorology and chamber measurements to both calculate fluxes and obtain samples for pilot isotopic analyses.

**TASK OBJECTIVE**: The remote sensing pilot will examine Fourier Transform Infrared (FTIR) spectroscopy, Laser spectroscopy and hyperspectral imaging/spectroscopy methods to determine suitability for ground based or airborne measurements of seeps. A range of new, cheaper sensors are appearing on the market and these will be evaluated along with existing methods to determine best approach for this application. This will require resolving a suite of technical difficulties and questions associated with each method and testing them against diffuse, low concentration sources of methane in the atmosphere.

**TASK OUTPUTS**: Report on application of methods at pilot sites and recommendations for establishing baseline measurements

## PROGRESS REPORT:

The interim report for Phase 2 (which only relates to the remote sensing component) has been through the mandatory internal review and was submitted to APPEA on 11 November 2014.

## Task 2.2

**TASK NAME: Ground detection pilot study**

**TASK LEADER**: Stuart Day

**OVERALL TIMEFRAME**: It is proposed that Task 2 be undertaken over 8 months and be finished at 12 months.

**BACKGROUND**: Task 2 consists of utilising knowledge gained in Task 1 to deploy methods at pilot test sites. Prior to deployment at pilot sites, model testing is required to ensure the best application of methods. Due to the highly uncertain nature of methane seeps in this region, a significant amount of interpretation and testing of numerical models will be required as part of the review process. It is important that characterization of the drivers of methane fluxes and their response processes can be understood and interpreted by source modelling. The review of methods will consider the measurements and numerical modelling requirements for work undertaken at three scales or 'footprints' of methane loss to the atmosphere:

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The pilot studies will be applied to methane sources using a combination of methods identified, developed, tested and refined in Task 1 and model testing in Task 2. Ground based methods potentially include atmospheric concentration measurements with accompanying meteorology and chamber measurements to both calculate fluxes and obtain samples for pilot isotopic analyses.

**TASK OBJECTIVE**: The on-ground pilot will utilise observations of atmospheric methane concentration as data constraints in models to determine fluxes from locations and their potential variation in response to known drivers. Inverse methods will be trialled at these pilot sites to obtain best estimates of source fluxes of methane and their variability. Inverse modelling is the most scientifically rigorous approach to examining the mechanisms driving variation in background methane fluxes. The modelling undertaken will form the bases for a scientifically robust interpretation of measurements and longer application of methods in Task 3 to establish baseline fluxes and their variations.

If the pilot site consists of methane fluxes from water bodies, the work will build on existing research undertaken in CSIRO in the Condamine River. Methane fluxes from aquatic systems with free water surfaces (e.g. river weir pools, farm dams) will be quantified using floating chambers used in one of two modes:

1) For low fluxes typical of natural waters the head-space gas is recirculated through a high precision gas analyser (Picarro CRDS) following the protocols used by CSIRO for similar research in water supply reservoirs;

2) For high fluxes (i.e. vigorous bubbling), a once-through system currently being developed and trialled by CSIRO will be employed in which gas captured by a chamber is diluted by ambient air drawn through the chamber and subsequently analysed using a high precision gas analyser.

Initial sampling is to be conducted at a coarse spatial resolution to identify important spatial gradients in fluxes. Subsequent sampling will be undertaken at higher spatial resolution to reduce uncertainty in the overall areal mean flux to within satisfactory levels. Adequate characterisation of instantaneous fluxes from a weir pool experiencing decomposition of catchment-supplied organic matter can be completed in 1-2 days of sampling (depending on spatial scale; 1 day of sampling should be sufficient for volumes < 2000 ML). Characterisation of seasonal variability requires 3 to 4 sampling experiments and would be undertaken in Task 3. Interannual variability is likely to be very high in systems subject to flooding on an irregular basis as flood waters will supply large amounts of organic matter that will degrade rapidly over the first year but may continue to fuel methanogenesis at a lower rate for several years. Characterising interannual variability would require ongoing monitoring following Task 3.

At the pilot sites, flux chamber measurements, combined with limited isotopic analyses will be used to differentiate reservoir methane from other potential sources. Once started the isotope observations will enable planning for potentially more detailed sampling based on cost and importance (in Task 3). More extensive sampling and detailed work is planned in Task 3 depending on results from the pilot sites. Terrestrial sites may include soil-air space sampling and soil water sampling. Aquatic sites will include chamber measurements of fluxes, samples of bubble methane and associated samples of river water to measure dissolved methane concentrations. The geochemistry of these samples will assist with establishing sources of methane and flux measurements will determine quantities of methane generated per unit time.

Measurements of samples will consist of limited isotopic composition (such as 13CH4, CH3D, 14CH4), CH4 concentration in air, soils, water and direct from source, and a suite of geochemical elements as potential tracers to identify sources.

In aquatic sites, we will also conduct the following sampling and measurements:

- Collect and analyze (by ICPMS) water samples for basic geochemical constituents to characterize possible groundwater exchanges with the river.
- Collect and analyze water samples for 13C isotopes, alkalinity and TIC.
- Collect gas samples and analyze for composition (C1-C5, O2+Ar, N2, CO2, d13C - CH4, d2D - CH4)

Collect and analyze water samples to characterize the spatial variability of dissolved methane and compute any associated fluxes.

**TASK OUTPUTS & SPECIFIC DELIVERABLES**: Report on application of methods at pilot sites and recommendations for establishing baseline measurements

## PROGRESS REPORT:

The final report for Phase 2 (which includes the remote sensing and ground detection components) has been through the compulsory internal review. It is available on the GISERA website for viewing "Characterisation of Regional Fluxes of Methane in the Surat Basin, Phase 2: A pilot study of methodology to detect and quantify methane sources".

## Task 3.1 (revised tasks)

**TASK NAME: Continuous monitoring results, preliminary data and remote sensing trial**

**TASK LEADER:** Stuart Day

**OVERALL TIMEFRAME:** 12 months

**BACKGROUND:** Note that since the original project order it was agreed to run Phase 3 over three years (originally to be one year). This was to allow the baseline monitoring to extend over the period of expected increase in gas production from the Surat gas fields and to reveal any seasonal variability in emissions that would be difficult to discern from a 12-month monitoring campaign.

**TASK OBJECTIVE:**

i) The continuous monitoring results – installation, commissioning and operation of the two field stations.

ii) Preliminary data available.

iii) Trial of remote sensing technologies.

**TASK OUTPUTS:** Interim report on the atmospheric monitoring activities at the start of Phase 3.

## PROGROSS REPORT:

A progress report on the successful installation, commissioning and operation of the two fixed monitoring stations was provided to Rick Wilkinson on 23 December 2015. This report also included a description of a remote sensing trial that was originally scheduled for Task

3.2. The remote sensing work was brought forward to take advantage of an opportunity to trial a hyperspectral instrument that was in Australia for a brief period during May and June 2015.

## Task 3.2

**TASK NAME: Modelled development and analysis and period monitoring**

**TASK LEADER:** Stuart Day

**OVERALL TIMEFRAME:** 12 months

**BACKGROUND:** Note that since the original project order it was agreed to run Phase 3 over three years (originally to be one year). This was to allow the baseline monitoring to extend over the period of expected increase in gas production from the Surat gas fields and to reveal any seasonal variability in emissions that would be difficult to discern from a 12-month monitoring campaign.

**TASK OBJECTIVE:**

i) Modelled development and analysis of continuous data.

ii) Periodic monitoring and field validation

**TASK OUTPUTS:** Interim Report on progress of Phase 3.

### PROGRESS REPORT:

This milestone is completed.

The atmospheric model has been set up for the Surat Basin region.

The inverse platform has been developed to be able to infer emissions from concentrations and meteorological data (from 3.1, 4.1 and 4.2). Preliminary inversions and their results are being assessed.

The interim report is complete and the main findings were presented at the GISERA/CSIRO workshop on the measurement and management of methane from the gas industry (CSIRO North Ryde, May 3, 2017). Suggestions were taken into account, and a revised version has been internally reviewed in CSIRO O and A and further improved. The interim report is available for viewing on the GISERA website Characterisation of Regional Fluxes of Methane in the Surat Basin, Phase 3.1: monitoring results

## Task 3.3

**TASK NAME: Final report for Remote sensing baseline study and Ground detection baseline study**

**TASK LEADER:** Stuart Day

**OVERALL TIMEFRAME:** 12 months

**BACKGROUND:** Note that since the original project order it was agreed to run Phase 3 over three years (originally to be one year). This was to allow the baseline monitoring to extend over the period of expected increase in gas production from the Surat gas fields and to reveal any seasonal variability in emissions that would be difficult to discern from a 12-month monitoring campaign.

**TASK OBJECTIVE:** Delivery of final report for Remote sensing baseline study and Ground detection baseline study

**TASK OUTPUTS:** Final report for Remote sensing baseline study and Ground detection baseline study.

## PROGRESS REPORT:

Edits to the final report have been made, addressing comments from 3 reviewers and discussions with GISERA director. Some new material has been included in the report as a result.

## Task 4.1

**TASK NAME: Prepare new data**

**TASK LEADER:** David Etheridge

**OVERALL TIMEFRAME:** 30.11.2015-30.11.2016

**BACKGROUND:** Data from Ironbark and Burncluith stations should be available and complemented by additional tracer gas measurements from the new industry air quality monitoring stations (including Origin's Hopelands). Field surveys will be undertaken and data made available.

**TASK OBJECTIVE:** Compile and calibrate new station concentration data to include with Ironbark and Burncluith. Compile emissions and flux information from field surveys (from Phase 2 and from new tasks) to inform modelling.

**TASK OUTPUTS & SPECIFIC DELIVERABLES:** Calibrated data sets of greenhouse gas concentrations and tracer gases across a network of stations in the Surat Basin. Data base of locations and emissions strengths of known sources to inform forward and inverse modelling.

## PROGRESS REPORT:

This milestone is 100% completed.

Calibrated data sets of greenhouse gas and tracer gas concentrations across the Surat Basin (Ironbark and Burncluith) are available and being used in 3.2. Origin's Hopelands station has been added to the inverse modelling platform and data are awaiting calibration from Ecotech. A data base of locations and emissions strengths of known sources to inform forward and inverse modelling has been compiled for CSIRO by consultant Katestone. A draft report incorporating inventory emissions and CSIRO survey data for methane sources other than CSG has been prepared by Katestone and is being reviewed by CSIRO. CSG sources will be added to the inventory by Katestone when provided to them by industry.

## Task 4.2

**TASK NAME: Screen and evaluate data**

**TASK LEADER:** David Etheridge

**OVERALL TIMEFRAME:** 30.11.2015-30.11.2016

**BACKGROUND:** Station data from Task 4.1 available.

**TASK OBJECTIVE:** To screen and filter data and develop techniques to identify confounding local sources such as livestock, vehicles, power plants and fires, using multiple species concentrations, tracer gases and information on wind trajectories, Identify the underlying main source signals in the screened data.

**TASK OUTPUTS & SPECIFIC DELIVERABLES:** Screened data sets from the ground based atmospheric monitoring network, which will then be used for modelling. Main source locations identified.

## PROGRESS REPORT:

This milestone is 100% completed.

The concentration data from Ironbark and from Burncluith have been filtered to remove unwanted signals from nearby cattle for input to the forward and inverse modelling in 3.2. Wind sectors, wind speed and time of day selection criteria have been evaluated and applied. Main source directions have been identified and incorporated into the 3.2 interim report which will be released following internal review.

## Task 4.3

**TASK NAME: Develop and apply models**

**TASK LEADER:** Ashok Luhar

**OVERALL TIMEFRAME:** 1.7.2016-1.8.2017

**BACKGROUND:** This task requires source locations and emissions strengths from field surveys; Screened and evaluated concentration data from Task 4.2; Meteorological and flux data from Ironbark and Burncluith stations and emerging industry stations (Origin's Hopelands).

**TASK OBJECTIVE:** Develop the modelling framework for the Surat Basin, using TAPM (CSIRO meteorological and dispersion model) in forward and inverse modes. Use predicted concentration fields from forward modelling simulations of prior source estimates from Phase 2 as initial conditions. Constrain atmospheric transport with meteorological and flux station data. Include known sources in the model and compare with observations over the GISERA monitoring period. Identify and estimate emissions from main source areas not previously known or identified in field surveys. Attribute source type using multiple gas species and follow up ground surveys.

**TASK OUTPUTS & SPECIFIC DELIVERABLES:** A modelling capability to infer methane sources across the Surat Basin with more definitive information on source locations and types than would be available from the baseline atmospheric monitoring and modelling in Phase 3. Reports, presentations and a draft journal publication on the technique and the findings.

## PROGRESS REPORT:

Continuous measurements of methane, carbon dioxide and meteorology have been taken at two fixed monitoring stations established across a large segment of the Surat Basin, on either side of existing and future-projected CSG activity. Ironbark (to the southwest) and Burncluith (to the northeast). See Day et al. (2015) and Etheridge et al. (2016, 2017).

Measurements at Ironbark since November 2016 were affected by frequent and prolonged site power outages. Measurements at Burncluith have continued without problems since installation of the station in July 2015.

The Ironbark and Burncluith monitoring facilities have also supported measurements of air quality gas species (by CSIRO and Ecotech) since the middle of 2016 and measurement of radon (by

ANSTO) from August to November 2017. There could be opportunities to use the information from each type of measurement in the data analysis.

The gas concentration measurements have been quality controlled and calibrated to CSIRO standards which are linked to internationally accepted World Meteorological scales. This allows data from both stations can be compared with each other and with data from other CSIRO monitoring such as the mobile Picarro monitoring (Day et al., 2015) and Australian network stations such as Cape Ferguson, Queensland. Small enhancements (as little as a few parts per billion methane) are then reliably interpreted in models as signals due to emissions.

The full period of gas concentrations from Ironbark and Burncluith have also been filtered for transient spikes resulting from the occasional presence of cows in the immediate vicinity of the analyser inlets without altering the underlying signals and trends in methane concentration due to the more significant sources in the region (Etheridge et al., 2017).

The processed data provide nearly continuous records from 19 March 2015 to 29 November 2016 at Ironbark and from 14 July 2015 to the present at Burncluith. This allows a period of 16 months when data from both stations can be used together in modelling. The two measurement sites are used as either an upwind-downwind configuration for background-subtracted signals when the wind direction is aligned between the sites, or as two independent sites in the inverse derivation of source emissions with the background concentration specified (Etheridge et al., 2017).

A "bottom-up" inventory of all expected methane emissions has been compiled in conjunction with consultants Katestone Environmental. It sourced emissions data from publically-available databases, inventories and reporting, from CSIRO survey data, and from CSG companies. Emissions are calculated from activities and emissions factors across a domain of 344 km by 345 km centred near Miles. Source categories are agriculture (feedlots, grazing cattle, poultry, piggeries), wood heating, landfills, coal mining, motor vehicles, power stations, river and ground seeps, waste water treatment and coal seam gas (processing and production).

Company-specific CSG data provided to Katestone for this work will remain confidential to CSIRO. Any reports or publications resulting from the use of the emissions inventory will not contain company-specific information. An internal review of the methodology of the inventory is being carried out.

A computer code has been developed to process the bottom-up Katestone emissions data in the format required by CSIRO's regional transport model TAPM. These processed emissions are being used in forward transport runs to determine concentration contributions from the specified emission sectors. The processed emissions are also be used as prior knowledge in the inverse modelling to estimate emissions in Surat Basin based on the concentration measurements from the Ironbark and Burncluith stations.

The final data set of concentrations and meteorology measurements and the emissions inventory are being used in a number of model experiments and simulations:

Forward simulations using CSIRO's TAPM model with Katestone emissions produce concentration time series for comparison with the measured concentrations at Ironbark and Burncluith. A "synthetic" inverse modelling case then uses the concentration time series output for the two stations from the above forward model run to "recover" the corresponding emissions, for comparison with the original Katestone emissions.

Another inversion will use only the measured concentrations to derive emissions, which will be used in a forward simulation to test how well the concentrations are recovered to test the model meteorology and the inverse method. One more inversion will be performed with Katestone emissions as a prior.

When satisfied that model and inversions are performing sufficiently well based on the above simulations and tests, inversions will be run for the period of both-station concentration data to infer “top-down” emissions across the region.

Results so far have been presented at the European Geophysical Society General Assembly and the GISERA annual workshop. A paper has also been accepted for the Australian Meteorological and Oceanographic Society (AMOS) National Conference Sydney from 5 to 9 February 2018. The report is available for viewing on the GISERA website Characterisation of Regional Fluxes of Methane in the Surat Basin, Phase 3.2

## Task 4.4

**TASK NAME: Report on enhanced monitoring.**

**TASK LEADER:** David Etheridge

**OVERALL TIMEFRAME:** 1.12.2016-30.11.2017

**BACKGROUND:** Successful progress on Tasks 4.1-4.4

**TASK OBJECTIVE:** To report on atmospheric concentration monitoring network, field surveys, modelling framework and inferred source information from enhanced monitoring and modelling program.

**TASK OUTPUTS & SPECIFIC DELIVERABLES**: Report on enhanced monitoring and modelling project to GISERA, possibly combined with final report (Task 3.3).

## PROGRESS REPORT:

A comprehensive report presenting the monitoring results from 2 stations, model framework, bottom-up inventory from databases and from ground surveys, and forward and inverse model results giving inferred methane emissions across a large region of the Surat Basin has been completed and entered into ePublish for review.